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This report contains the results of a study of air emissions from hospital waste combustion. These results will allow the EPA to assess the need for and feasibility of regulating multipollutant emissions from hospital waste combustion.

Information was gathered from State and local environmental agencies, equipment vendors, the open technical literature, the American Hospital Association, and visits to three incineration facilities. Information was sought concerning feed characteristics, combustor designs and operating characteristics, emissions of air pollutants, applied and potential control technology, numbers and locations of hospital waste combustors, and applicable regulations.

A final draft report was widely circulated by EPA/OAQPS for review and comments. Comments received were evaluated and incorporated into this report where appropriate.

The report provides a description of the industry and characterization of hospital waste, information about the processes and equipment used for hospital waste combuation, data concerning air pollutants emitted from hospital waste incinerators and their formation in the combustion process, a discussion of air pollution control techniques and possible control efficiencies, a summary of regulations affecting hospital waste combustion and model plants for EPA's use in assessing regulatory strategies.

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Final Report

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1.0 INTRODUCTION

This report contains the results of a study of air emissions from hospital waste combustion. It represents an effort to gather currently available data in a manner that will allow the EPA to assess the need for and feasibility of regulating multipollutant emissions from hospital waste combustion. The work was performed by Radian Corporation under contract to EPA's Pollutant Assessment Branch of the Office of Air Quality Planning and Standards (OAQPS).

During the course of this study, information was gathered from State and local environmental agencies, from vendors of incineration equipment, from the open technical literature, from the American Hospital Association, and from visits to three incineration facilities. Information was sought concerning feed characteristics, combustor designs and operating characteristics, emissions of air pollutants, applied and potential control technology, numbers and locations of hospital waste combustors, and applicable regulations. In addition, parameters needed to model exposure and health risk have been developed for use in EPA's Human Exposure Model.

A final draft report for this study was prepared in October 1987. This report was widely circulated by EPA/OAQPS for review and comments by EPA Regional Offices, State agenices, related trade associations, incinerator vendors, and interested individuals. Comments received were evaluated and incorporated into this report where appropriate. While some new emissions data were received, they were of a preliminary nature and thus have been reported as a separate category of data in Section 3.

The remainder of Section 1 is devoted to a description of the industry (Section 1.1) and characterization of hospital waste (Section 1.2). Section 2.0 contains information about the processes and equipment used for hospital waste combustion. Data gathered concerning air pollutants emitted from hospital waste incinerators and their formation in the combustion process are presented in Section 3.0. Section 4.0 contains a discussion of control techniques and possible control efficiencies. environmental regulations affecting hospital waste combustion are presented in Section 3.0. Section 4.0 contains a discussion of control techniques and possible control efficiencies. Environmental regulations affecting hospital waste combustion are presented in Section 5.0. Model plants suitable for EPA's use in assessing regulatory strategies are developed in Section 6.0.

1.1 DESCRIPTION OF THE INDUSTRY

"Hospital waste" refers to wastes produced by a hospital or hospital-type facility. These wastes include both infectious wastes (i.e., materials which come in contact with hospital patients and which have a potential to carry disease-producing organisms) and non-infectious or general housekeeping wastes. The volume of infectious waste produced by a facility can vary widely, depending primarily on guidelines or practices employed. Based upon CDC guidelines, infectious waste would only comprise 3 to 5 percent of the total hospital waste.[1] Conversely, hospital infectious waste could comprise 80 percent or more of total waste based upon the Universal Isolation Precaution Guidelines of August 1987. In addition to these guidelines, the waste segregation practices employed by hospitals will influence the total volume of waste which is considered infectious. Although segregation of infectious and non-infectious waste introduces additional handling complications and expense, comments received from the American Society for Hospital Engineering (of the American Hospital Association) indicate that most hospitals have waste segregation programs in place.[2]

In many States, laws have been enacted in the past ten years which prohibit the disposal of infectious wastes in landfills. To qualify for disposal, wastes must first be rendered innocuous. The two primary sterilization methods used by hospitals are autoclaving and incineration. Sterilization with ethylene oxide and waste shredding followed by chemical disinfection are available alternatives but are not commonly used. Due to limitations associated with autoclaving (i.e., limited capacities, handling problems, and questionable effectiveness) and ethylene oxide units (i.e., worker health risks), incineration has become the most practical waste sterilization and disposal option for many hospital facilities,[3] according to authorities in Illinois.

Incineration reduces waste volumes by up to 90 percent. Hence, the volume and cost of ultimate disposal of residual wastes in a landfill can be reduced significantly by this method. An additional benefit of incineration systems, in some cases, is that they can be designed for heat recovery with the potential to supply a portion of the hospital's steam or hot water requirements.

The total number and capacity of hospital waste incinerators in the United States is uncertain. As of 1985, there were a reported 6,872 hospitals in the nation with 1,318,000 beds.[4] Estimates of waste generation rates range from about 8 to 45 lb/bed/day.[5],[6],[7] For example, Table 1-1 shows hospital waste generation per bed for seventeen hospitals in the State of Florida. The waste generation rate for these seventeen hospitals ranged from 8 to 45 lb/bed/day and averaged 23 lb/bed/day. Using this average generation rate and an average occupancy rate of 69 percent, the total hospital waste generation rate in the United States is estimated to be about 10,500 tons/day. However, not all hospital waste is sent to incinerators, as discussed above. To estimate actual incinerator tonnage, this rate would need to be reduced by the amount of infectious waste handled by other treatment processes and the amount of general waste that is segregated and sent via trash disposal to landfills. Unfortunately, it is not possible to estimate these quantities based on the information gathered to date. As a point of reference, however, about 18,000 tons/day of municipal solid waste were disposed of by combustion by municipalities in 1985.[8]

With regard to geographic distribution, hospitals are located in every State as well as in the District of Columbia. At least one hospital was located in almost all metropolitan and non-metropolitan statistical areas in 1985 according to American Hospital Association statistics[9] Of the total number of hospitals, approximately 53 percent were located in metropolitan statistical areas with the balance in non-metropolitan areas.

Detailed statistics are available only for community hospitals, which comprised over 83 percent of the total number of hospitals in 1985. During the 1975 to 1985 period, the number of community hospitals declined by 2.4 percent; the total number of beds increased by 6.2 percent, however, a shift attributed to hospital closures, mergers, and conversion to nonacute-care facilities.[10] Although the occupancy rate for community hospitals declined from 75 to about 65 percent, the number of surgical operations (which produce higher levels of infectious waste) increased by almost 21 percent. Taking these off-setting factors into account, the

TABLE 1-1. WASTE GENERATION RATES FOR SEVENTEEN HOSPITALS IN THE STATE OF FLORIDA[a]

Hospital	Pathological	Infectious	General	Food	Cardboard	Total	Average # Beds	#/Bed/Day
Miami Jewish Home & Hospital	—	23	1,350	6,120	405	7,898	376	21
Coral Reef Hospital	—	320[b]	2,567[c]	—	—	2,887	127	23
Miami General	2	685	3,570[e]	—	—	4,257	237	18
North Ridge General	17	95	3,440[d]	—	301	3,853	168	23
South Miami Hospital	—	300	3,400	1,700	567	5,967	350	17
Cedars Medical Center	—	900	6,800	500	1,000	9,200	355	26
American Hospital of Miami	—	3,140	4,586[c]	—	—	7,726	300	26
Bascom Palmer Eye Institute	—	103[b]	2,304[c]	—	—	2,407	100	24
Larkin General Hospital	10%	15%	55%	10%	10%	N/A	60	N/A
Miami Children's	3	103	1,413	100	1	1,620	137	12
Grant Center Hospital	—	93	1,800[e]	2,592	—	4,485	100	45
North Gables Hospital	7	4.7	205	630	29	876	53	16.5
Miami Heart Institute	—	1,200[b]	7,440[c]	—	—	8,640	191	45
Pembroke Pines General	21	137	1,350[c]	—	—	1,508	195	8
James Archer Smith	29	857	143	71	143	1,243	80	16*
Baptist Hospital of Miami	1,500	750	5,500	4,500	2,000	14,250	383	37*
Doctor's Hospital	—	333[b]	2,160[e]	3,888	—	6,381	165	39*

[a] Reference 7. Rates are in lb/day unless noted otherwise.

[b] Amount includes Pathological wastes.

[c] Amount includes Food and Cardboard wastes.

[d] Amount includes Food wastes.

[e] Amount includes Cardboard wastes.

*These questionnaires arrived after the computations were completed and so are not included in the average lbs/bed/day figure.

overall hospital waste generation rate appears to have remained relatively constant over this 10-year period. No factors were identified which would significantly change this trend in the near future.

No comprehensive information was found during this study regarding the total population of hospital waste incinerators in the nation. One manufacturer's representative estimated that over 90 percent of operating hospitals have an incinerator on-site, if only a small retort-type unit for pathological or special wastes.[11] The number of larger, controlled air type incinerators operating on hospital wastes is not known. However, based on discussions with two of the leading controlled-air incinerator manufacturers, it is estimated that at least 1,200 of these systems have been installed at United States hospitals over the past 20 years.[12,13] This implies that there are approximately 5,000 retort-type incinerators installed. While some of these units have been retired, a great majority are felt to be currently in operation.[14]

Some insight into the incineration population distribution was gained by examining a recent New York State data base which was developed from an in-state survey of over 400 hospital waste incinerator units. This data base, and the analysis conducted by Radian Corporation during this study, are described in detail in Section 6.1. Highlights of the analysis are as follows:

- Almost 60 percent of the New York incinerators have design feed capacities of less than 200 lb/hr.
- The population distribution is bimodal with respect to feed capacity, with peaks in the 50 to 74 lb/hr range and in the 100 to 124 lb/hr range.
- About 14 percent of the incinerator population in New York is above 600 lb/hr feed capacity and about 6.5 percent is above 1,000 lb/hr feed capacity.

A comparison of the New York and total U.S. hospital populations indicates that the two populations have similar overall distributions although there is a greater proportion of large hospitals above the 500-bed size in NY than in the nation as a whole. The conclusions drawn from this analysis is that there are many small hospital waste incinerators but that the larger incinerators account for a significant fraction of total waste handling capacity.

1.2 WASTE CHARACTERIZATION

Hospital waste is characteristically heterogeneous, consisting of objects of many different sizes and composed of many different materials. The daily activities and procedures within a hospital can vary dramatically from day-to-day, thus making it difficult to predict what will be thrown away. During the course of this study, very little data were found on the composition of hospital waste. This may be due to the fact that the amount of sampling and chemical analyses required to generate representative characterization data would be extensive and costly. In addition, industry practice for many years has been to utilize the simplified waste classification system developed by the Incinerator Institute of America (IIA), discussed below, rather than to sample and chemically analyze waste. Table 1-2 contains one general breakdown of the composition of typical hospital waste.

As discussed above, the experience of hospitals in Illinois indicates that above 85% of a hospital's waste stream can be categorized as general refuse, while the remaining 15% is contaminated with infectious agents.[15] This is only a generalization, however, and actual wastes from a given hospital can vary significantly from day to day and from hour to hour. For example, refuse collected after a major surgical procedure, such as a heart transplant, may contain significantly more infectious wastes and disposable plastics than is usually generated in a routine operation.[16] Also, to the extent that the infectious waste is mixed with a hospital's general waste, more waste will be generated that is considered infectious.[17]

Most of the public attention concerning hospital waste management has centered on infectious waste. Unfortunately, a number of general and vague terms are used to refer to these wastes, including "pathological waste," "biological waste," "hazardous waste," "biomedical waste," and "contaminated waste." In Canada, the term biomedical waste is popular and a color-code classification scheme for the waste has been developed as shown in Table 1-3. In the United States, all these categories of wastes are generally classified as "red bag" waste.[18]

TABLE 1-2. HOSPITAL WASTE CHARACTERIZATION[a]

Product	Approximate Percent by Weight[b]
Paper	65
Plastic	30
Moisture	10
Other	5

[a] Reference 19.

[b] Percentages do not add to 100 since they are approximations.

TABLE 1-3. CANADIAN CHARACTERIZATION OF BIOMEDICAL WASTE[a]

Waste Class	Component Description	Typical Component weight percent (as fired)
A1 (Red Bag)	Human Anatomical	95-100
	Plastics	0-5
	Swabs, Absorbents	0-5
	Alcohol, Disinfectants	0-0.2
A2 (Orange Bag)	Animal Infected Anatomical	80-100
	Plastics	0-15
	Glass	0-5
	Beddings, Shavings, Paper, Fecal Matter	0-10
A3a (Yellow Bag)	Gauze, Pads, Swabs, Garments, Paper, Cellulose	60-90
	Plastics, PVC, Syringes	15-30
	Sharps, Needles	4-8
	Fluids, Residuals	2-5
	Alcohols, Disinfectants	0-0.2
A3b (Yellow Bag) Lab Waste	Plastics	50-60
	Sharps	0-5
	Cellulose Materials	5-10
	Fluids, Residuals	1-20
	Alcohols, Disinfectants	0-0.2
	Glass	15-25
A3c (Yellow Bag) R&D on DNA	Gauze, Pads, Swabs	5-30
	Plastics, Petri Dishes	50-60
	Sharps, Glass	0-10
	Fluids	1-10
B1 (Blue bag)	Non-infected Animal Anatomical	90-100
	Plastics	0-10
	Glass	0-3
	Beddings, Shavings, Fecal Matter	0-10

[a] Reference 6.

In Europe, hospital wastes are divided into the general categories of normal housekeeping wastes and "hazardous" wastes. The latter category consists of bacterially infected pathological waste, oil and chemical waste, and radioactive isotopic contaminated waste.[20] A typical cross-section of this type of waste has included the following items:

Disposable linens
Paper
Flowers
Waste food
Cans
Diapers
Plastic cups
Syringes
Scalpels
Tweezers
Rubber gloves
Pathological objects
Blood test tubes
Test tubes from miscellaneous service
Petri dishes
Dropper bottles
Medicine bottles
Drop infusion equipment
Transfusion equipment
Suction catheters
Bladder catheters
Urinal catheters
Colostomi bags

The general practice in the United States is to classify wastes according to the IIA system described in Table 1-4. The popularity of this system is reinforced by the fact that most incinerator manufacturers rate their equipment in terms of these categories.[21]

While useful for general design purposes, the IIA classification scheme does not address concerns such as the plastics content of waste or possible hazardous components. Hospital wastes typically can contain about 20 percent plastics with levels as high as 30 percent being reported.[22] The types of plastic most commonly encountered include polyethylene, polypropylene, and polyvinyl chloride.[23] Potential combustion products from the burning of these plastics, including hydrochloric acid and toxic air contaminants, are discussed in Section 3.1. Ultimate analyses for four common plastics are shown in Table 1-5.

Hospital waste may also contain potentially toxic components. For example, red bag waste in the United States may contain potentially toxic compounds generated by hospital operations that are currently exempt from regulations under the Resource Conservation and Recovery Act (RCRA).[24] Such chemicals include waste pharmaceuticals, cytotoxic agents used in chemotherapy, and anti-neoplastic agents.[25] Mercury from dental clinics and other heavy metals used in hospitals may also cause air emission concerns if they enter the combustor along with other hospital wastes.

TABLE 1-4. INCINERATOR INSTITUTE OF AMERICA SOLID WASTE CLASSIFICATIONS[a]

Type 0	Trash, a mixture of highly combustible waste such as paper, cardboard, cartons, wood boxes, and combustible floor sweepings from commercial and industrial activities. The mixtures contain up to 10 percent by weight of plastic bags, coated paper, laminated paper, treated corrugated cardboard, oily rags, and plastic or rubber scraps. This type of waste contains 10 percent moisture, 5 percent incombustible solids and has a heating value of 8,500 Btu per pound as fired.
Type 1	Rubbish, a mixture of combustible waste such as paper, cardboard cartons, wood scrap, foliage, and combustible floor sweepings, from domestic, commercial, and industrial activities. The mixture contains up to 20 percent by weight of restaurant or cafeteria waste, but contains little or no treated papers, plastic, or rubber wastes. This type of waste contains 25 percent moisture, 10 percent incombustible solids, and has heating value of 6,500 Btu per pound as fired.
Type 2	Refuse, consisting of an approximately even mixture of rubbish and garbage by weight. This type of waste is common to apartment and residential occupancy, consisting of up to 50 percent moisture, 7 percent incombustible solids, and has a heating value of 4,300 Btu per pound as-fired.
Type 3	Garbage, consisting of animal and vegetable wastes from restaurants, cafeterias, hotels, hospitals, markets and like installations. This type of waste consists of up to 70 percent moisture, up to 5 percent incombustible solids, and has a heating value of 2,500 Btu per pound as-fired.
Type 4	Human and animal remains, consisting of carcasses, organs, and solid organic wastes from hospitals, laboratories, abattoirs, animal pounds, and similar sources, consisting of up to 85 percent moisture, 5 percent incombustible solids, and having a heating value of 1,000 Btu per pound as fired.

TABLE 1-4. INCINERATOR INSTITUTE OF AMERICA SOLID WASTE CLASSIFICATIONS[a] (Continued)

Type 5	Byproduct waste, gaseous, liquid or semiliquid, such as tar, paints, solvents, sludge, fumes, etcs., from industrial operations. Btu values must be determined by the individual materials to be destroyed.
Type 6	Solid bydproduct waste, such as rubber, plastics, wood waste, etc., from industrial operations. Btu values must be determined by the individual materials to be destroyed.

[a] Reference 26.

TABLE 1-5. ULTIMATE ANALYSES OF FOUR PLASTICS[a]
(Weight Percent)

	Polyethylene	Polystyrene	Polyurethane	Polyvinyl Chloride
Moisture	0.20	0.20	0.20	0.20
Carbon	84.38	86.91	63.14	45.04
Hydrogen	14.14	8.42	6.25	5.60
Oxygen	0.00	3.96	17.61	1.56
Nitrogen	0.06	0.21	5.98	0.08
Sulfur	0.03	0.02	0.02	0.14
Chlorine	tr	tr	2.42	45.32
Ash	1.19	0.45	4.38	2.06
Higher heating value, Btu/lb	19,687	16,419	11,203	9,754

[a]Reference 27.

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2.0 PROCESSES AND EQUIPMENT

The primary objectives of hospital waste incinerators are (1) to render the waste innocuous, and (2) to reduce the size and mass of the waste. These objectives are accomplished by exposing the waste to high temperatures over a period of time long enough to destroy threatening organisms and by burning all but the incombustible portion of the waste. As discussed in Section 1.1, incineration has become the primary sterilization and disposal option for many hospital facilities.

The design of a hospital waste incinerator, like any combustion system, requires consideration of a number of interrelated factors including residence time, temperature, and turbulence (i.e., the three "T"'s of combustion). Other factors which can influence combustion performance are fuel feeding patterns, air supply and distribution, heat transfer, and ash disposal.[1] Like municipal solid waste (MSW), hospital waste is a difficult fuel to combust relative to conventional fuels such as oil, gas, coal, or wood. Some of the problems associated with hospital wastes which must be considered by the combustion system designer and equipment operator are:

- Fuel of non-homogenous and variable composition - The physical and chemical composition of hospital waste is highly variable. Furthermore, the waste feed consists of chemically diverse articles of different sizes and shapes. Hospital waste is seldom pre-processed; it is burned in bulk on a mass feed basis. Non-homogenous and variable compositions should be accounted for in system design and operation to ensure that these factors do not pose problems in feeding, flame stability, particle entrainment and emission control.

- Variable ash content - Hospital waste contains varying amounts of glass, metals and ceramics which are not consumed in the combustion process. Fluctuations in ash composition and combustion temperatures can lead to clinker formation, slagging and fouling in some systems. To avoid these problems, primary combustion chamber temperatures are generally maintained below 1800°F.[2] However, this tends to reduce carbon burnout and the overall energy utilization efficiency.

- Low heating value - Hospital wastes often have low heating values due to high moisture contents. This causes flame stability problems and, in some cases, it becomes necessary to fire an auxiliary fuel to maintain proper combustion conditions.

Alternately, dry waste batches (especially those with a high plastics content) can produce high flame temperatures which result in overheating of the hearth or other combustion system components. To avoid these problems, the combustion conditions (principally excess air, air distribution, and auxiliary fuel firing rate) must be controlled closely.

- Corrosive materials - Hospital wastes contain varying amounts of fluorine and chlorine, principally from plastics. The acid gases produced from the incineration of these materials can corrode combustion and air pollution control equipment, especially convective heat transfer tubes. For this reason, hospital incinerators should be constructed of corrosion - resistant materials.

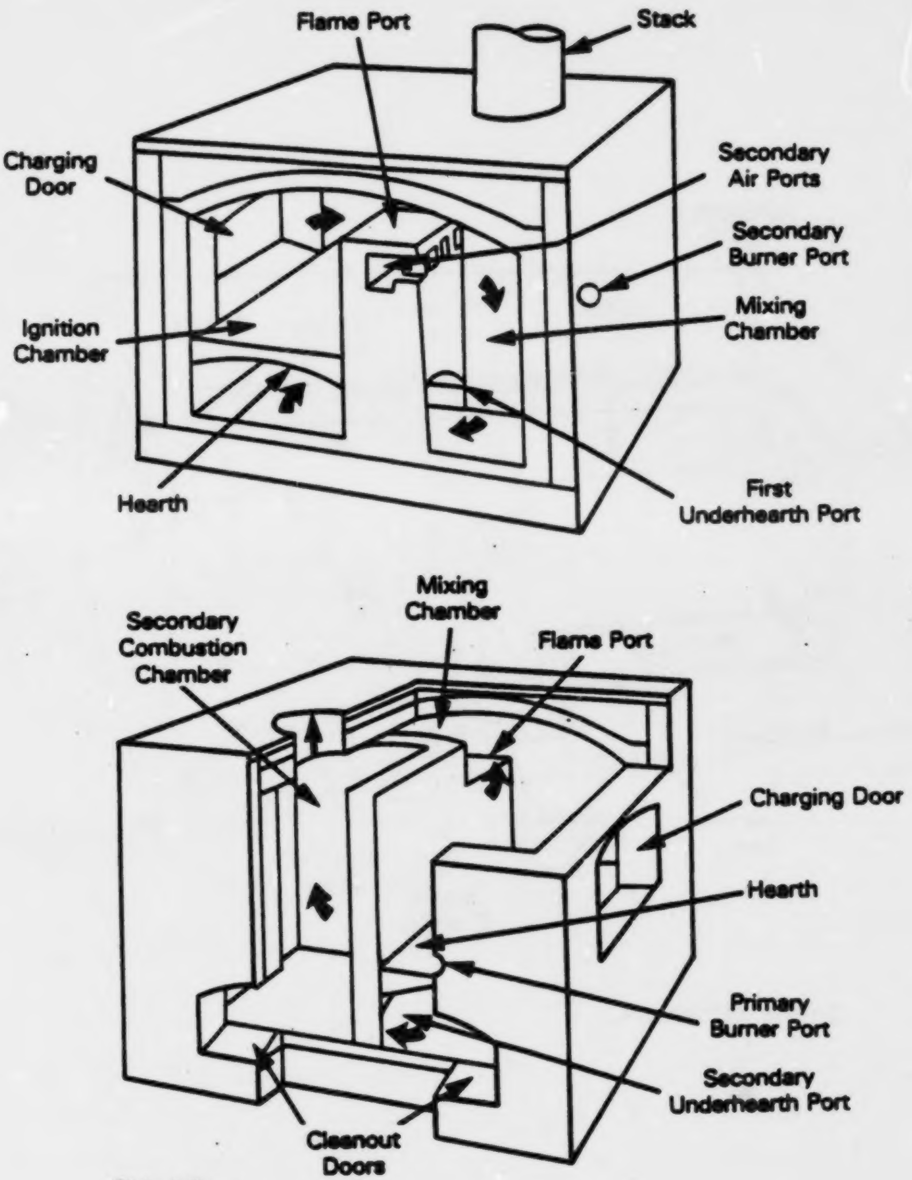
2.1 INCINERATOR TECHNOLOGY

There are three major types of incinerators currently used to incinerate hospital wastes in the United States: excess air, controlled air, and rotary kiln. The design and operating principles for each of these three major types are discussed in this section.

2.1.1 Retort Incinerators

Retort incinerators are variable capacity units which are mostly field fabricated. These units also typify older, existing hospital incinerators. They are also referred to as "pyrolitic," "multiple chamber," and "excess air" incinerators in the literature. These incinerators appear as a compact cube from the outside with a series of chambers and baffles on the inside. The two principal design configurations for retort incinerators are illustrated in Figures 2-1 and 2-2.

In both types of retort incinerators, combustion of the waste begins in the primary, or ignition, chamber. The waste is dried, ignited, and combusted by heat provided by a primary chamber burner as well as by hot chamber walls heated by flue gases. Moisture and volatile components in the waste feed are vaporized and pass, along with combustion gases, out of the primary chamber and through a flame port connecting the primary chamber to the secondary, or mixing, chamber. Secondary air is added through the flame port and is mixed with the volatile components in the secondary chamber.

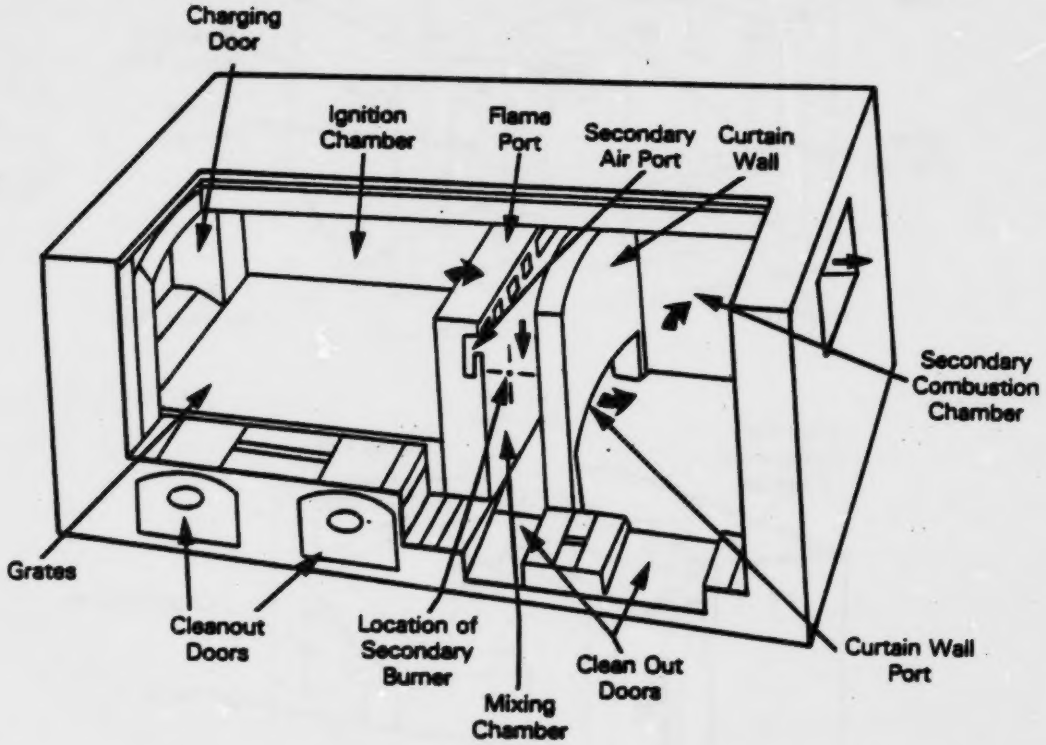

Flame Port
Stack
Charging Door
Secondary Air Ports
Secondary Burner Port
Ignition Chamber
Mixing Chamber
Hearth
First Underhearth Port
Secondary Combustion Chamber
Mixing Chamber
Flame Port
Charging Door
Hearth
Primary Burner Port
Secondary Underhearth Port
Cleanout Doors

Side View

Source: Reference 3.

Figure 2-1. Multiple-Chamber Pathological Waste Incinerator

0881469R


Charging Door
Ignition Chamber
Flame Port
Secondary Air Port
Curtain Wall
Secondary Combustion Chamber
Grates
Cleanout Doors
Location of Secondary Burner
Mixing Chamber
Clean Out Doors
Curtain Wall Port

Source: Reference 4.

Figure 2-2. In-Line Multiple-Chamber Incinerator

0981468R

Burners are also fitted to the secondary chamber to maintain adequate temperatures for combustion of the volatile gases. Incinerators designed to burn general hospital waste operate at total excess air levels of up to 300 percent; if only pathological wastes (i.e., animal and human remains) are combusted, excess air levels near 100 percent are more common.[5]

For in-line incinerators, combustion gases pass in a straight-through fashion from the primary chamber to the secondary chamber and out of the incinerator with 90 degree flow direction changes only in the vertical direction. The other common configuration for retort incinerators, on the other hand, causes the combustion gases to follow a more "tortuous" path through the incinerator with 90 degree flow direction changes in both the horizontal and vertical directions. These flow direction changes, as well as contraction and expansion of the combustion gases, enhance turbulent mixing of air and gases.[6] In addition, fly ash and other particulate matter drop from the gas stream as a result of the direction and gas velocity changes and collect on chamber floors. Gases exiting the secondary chamber are directed to the incinerator stack.

Retort incinerators are described as "unwieldy" by one source in sizes above 500 lb/hr capacity while in-line incinerators are felt to be most suitable in capacities of 750 lb/hr or greater.[7]

2.1.2 Controlled Air Incinerators

Controlled air incineration has become the most widely used hospital waste incinerator technology over the past 10 to 15 years and now dominates the market for new systems at hospitals and similar medical facilities.[8] This technology is also known as "starved air" incineration, "two-stage" incineration, and "modular" combustion. While there are some similarities in operating principles between retort and controlled-air incinerators, overall equipment design and appearance are quite different, as illustrated in Figure 2-3. The two-stage incinerator shown in Figure 2-3 is capable of 99.9 percent combustion efficiency.[9]

Like retort incinerators, combustion of waste in controlled air incinerators occurs in two stages. Waste is fed into the primary, or lower, combustion chamber which is operated, as the name implies, with less than the full amount of air required for combustion. Under these sub-stoichiometric

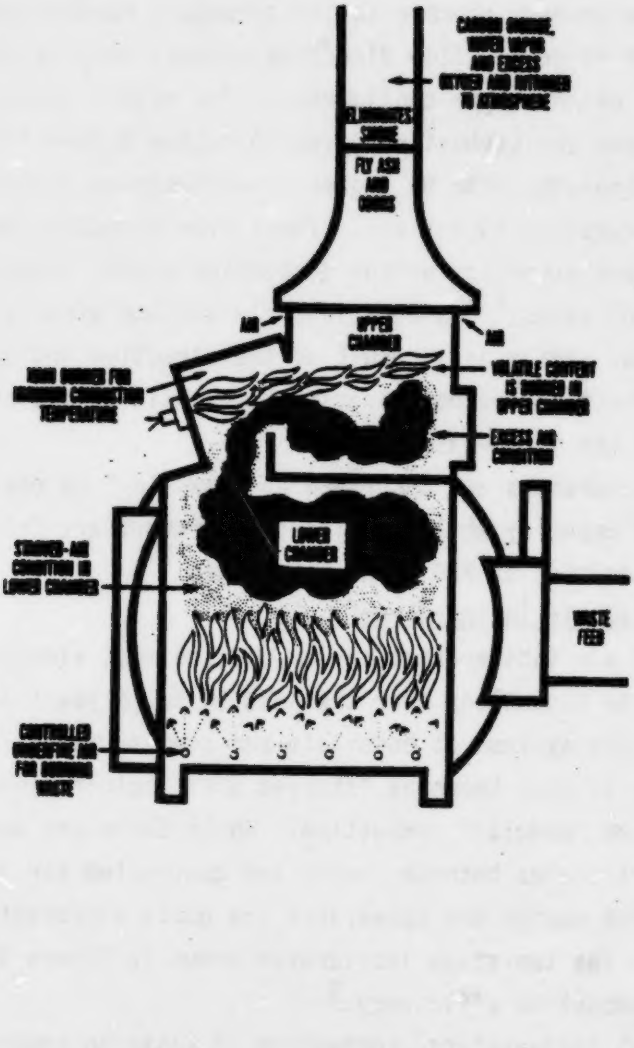

CARBON DIOXIDE, WATER VAPOR AND EXCESS OXYGEN AND NITROGEN TO ATMOSPHERE
ELIMINATES SMOKE
FLY ASH AND ODORS
AIR
UPPER CHAMBER
AIR
MAIN BURNER FOR MINIMUM COMBUSTION TEMPERATURE
VOLATILE CONTENT IS BURNED IN UPPER CHAMBER
EXCESS AIR CONDITION
LOWER CHAMBER
STARVED-AIR CONDITION IN LOWER CHAMBER
WASTE FEED
CONTROLLED UNDERFIRE AIR FOR BURNING WASTE

Figure 2-3. Schematic for Controlled Air Incinerator

conditions, the waste is dried, heated, and pyrolized, thereby releasing moisture and volatile components. The non-volatile, combustible portion of the waste is burned in the primary chamber to provide heat while the non-combustible portion accumulates as ash. Depending on the heating value of the waste and its moisture content, additional heat may be provided by auxiliary burners to maintain desired temperatures. Combustion air is added to the primary chamber either from below the waste through the floor of the chamber or through the sides of the chamber. The air addition rate is usually 40 to 70 percent of stoichiometric requirements.[10]

Because of the low air addition rates in the primary chamber, and corresponding low flue gas velocities and turbulence levels, the amount of solids entrained in the gases leaving the primary chamber is minimized. As a result, most controlled air incinerators can meet current State and local particulate matter emission limits without add-on gas cleaning devices.

Moisture, volatiles, and combustion gases from the primary chamber flow upward through a connecting section where they are mixed with air prior to entering the secondary, or upper combustion chamber. If the primary chamber gases are sufficiently hot, they will self-ignite when mixed with air. A second burner is located near the entrance to the upper chamber, however, to provide additional heat for ignition of the combustible gases and to maintain a flame in the chamber at all times of operation. Mixing of these gases with air is enhanced by the flow direction changes and contraction/ expansion step which the gases undergo as they pass from the lower to upper chambers. The air injection rate in the secondary chamber is generally between 100 and 140 percent of total stoichiometric requirements (based on the waste feed).[11] Thus, the total air added to both chambers can vary between 140 and 210 percent of stoichiometric requirements (i.e., between 40 and 110 percent excess air).

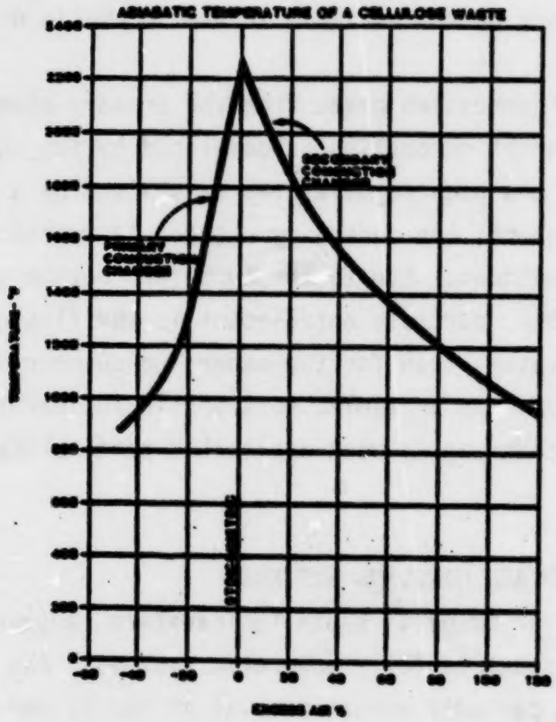
The secondary chamber burner is located near the entrance to this chamber to maximize the residence time of gases at high temperatures in this chamber. Bulk average gas residence times in the secondary chamber typically range from 0.25 to 2.0 second. Design exit gas temperatures generally range from 1400 to 2000°F.[12] Natural gas or distillate oil are the normal fuels used for both primary and secondary chamber burners. Temperatures in the primary and secondary chambers are monitored by thermocouples and controlled automatically by modulating the air flow to each chamber. Thermocouples are normally located near the exits of these chambers. In the primary (air-starved) chamber, combustion air flow is kept substoichimetric to release volatiles and to keep the gas velocities low to prevent particulates from going out through the secondary combustion chamber. In the secondary combustion chamber, air is generally increased to burn the volatile organics and to create extra turbulence to get mixing between the air and volatiles for proper combustion efficiencies. The logic for this control scheme is illustrated in Figure 2-4. Flue gases exiting the secondary chamber are sent either directly to a stack, to air pollution control equipment (if required), or to a waste heat recovery boiler.

Both the primary and secondary chambers are usually lined with refractory material. One manufacturer, however, offers a membrane water wall in the primary chamber. Most chambers are cylindrical; however, some are rectangular. Smaller units (i.e., with waste feed capacities less than 500 lb/hr) are usually vertically oriented with both chambers in a single casing. Larger units generally include two separate horizontal cylinders located one above the other.[13] Some manufacturers offer a third chamber for final air addition to the combustible gases and a fourth chamber for gas conditioning (i.e., gas cooling and condensation of vapors) to minimize effects on downstream heat recovery equipment or air pollution control equipment.[14]

Waste feed capacities for controlled air incinerators range from about 75 to 6500 lb/hr of Type 0 waste (at 8500 Btu/lb). Capacities for lower heat content wastes may be higher since feed capacities are limited by primary chamber heat release rates. Heat release rates for controlled air incinerators typically range from about 15,000 to 25,000 Btu/hr-ft^3.[16]

2.1.3 Rotary Kiln Incinerators

Like other incinerator types, rotary kiln incineration consists of a primary chamber in which waste is heated and volatilized and a secondary chamber in which combustion of the volatile fraction is completed. In this case, however, the primary chamber consists of a horizontal, rotating kiln. The kiln is inclined slightly so that the waste material migrates from the waste charging end to the ash discharge end as the kiln rotates. The waste migration, or throughput, rate is controlled by the rate of rotation and the



Source: Reference 15.

Figure 2-4. Adiabatic Temperature Versus Excess Air for a Controlled Air Incinerator

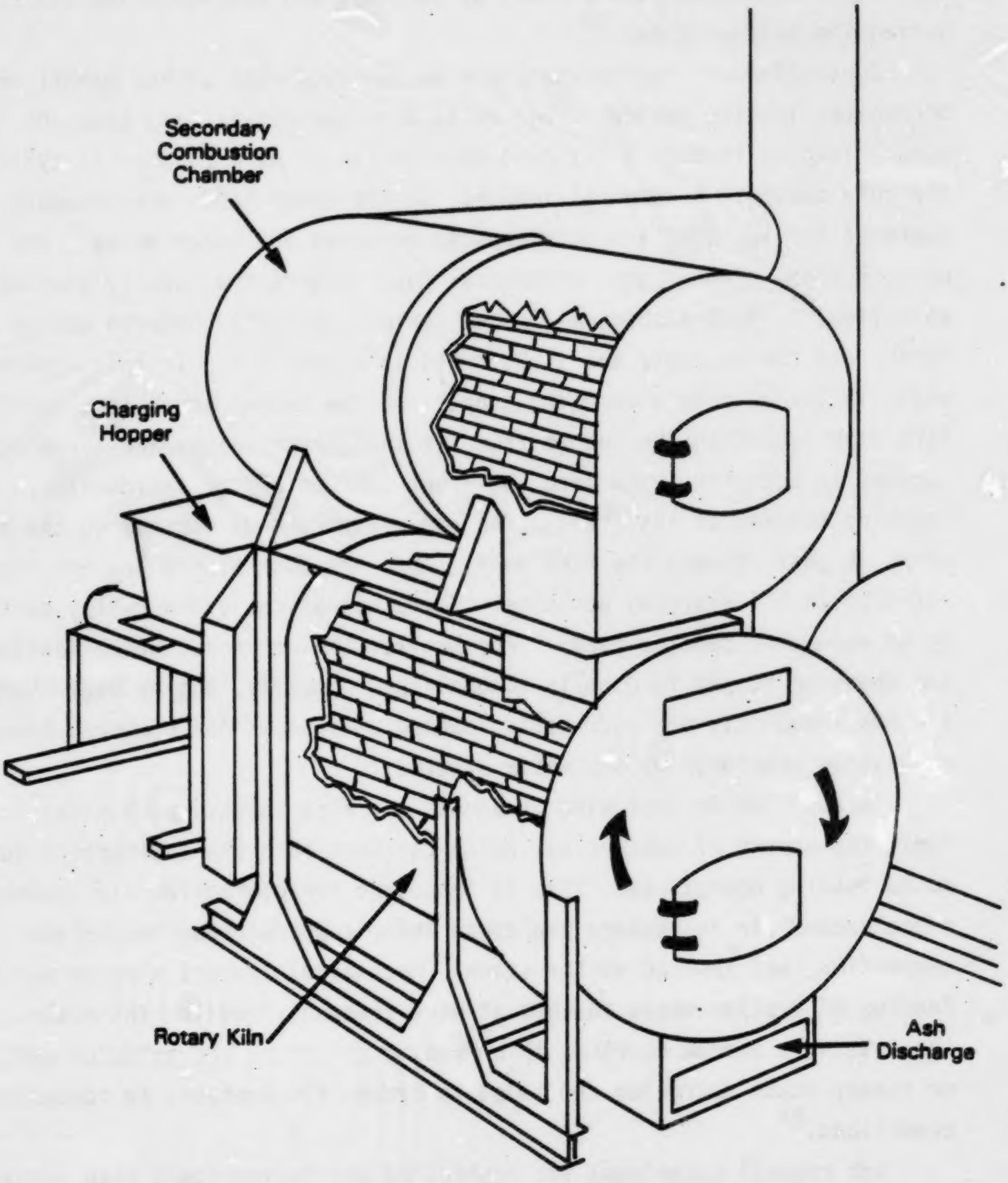
angle of incline, or rake, of the kiln. Air is injected into the primary chamber and mixes with the waste as it rotates through the kiln. A primary chamber burner is generally present for heat-up purposes and to maintain desired temperatures. Both the primary and secondary chambers are usually lined with refractory brick, as shown in the schematic drawing in Figure 2-5.

Volatiles and combustion gases from the primary chamber pass to the secondary chamber where combustion is completed by the addition of additional air and the high temperatures maintained by a second burner. Like other incinerators, the secondary chamber is operated at above-stoichiometric conditions. Due to the turbulent motion of the waste in the lower primary chamber, particle entrainment in the flue gases is higher for rotary kiln incinerators than for the other two chamber incinerator designs previously discussed. As a result, rotary kiln incinerators generally require stack gas clean-up to meet applicable particulate matter and/or opacity limits.[17]

2.2 WASTE FEED AND ASH HANDLING SYSTEMS

Feed systems for hospital waste incinerators range from manually operated charging doors to fully automatic systems. Ash removal systems also range between periodic manual removal of ash by operators to continuous automated quench and removal systems. In general, automated systems are prevalent among large continuously-operated incinerators while manual systems are employed on smaller incinerators or those which operate on an intermittent basis. Waste feed and ash removal systems are discussed below for each of the major incinerator design types.

For retort incinerators, waste loading is almost always accomplished manually by means of a charging door on the incinerator. The charging door is attached to the primary chamber and may be located either at the end farthest away from the flame port (for burning general wastes) or on the side (for units handling pathological wastes such as large animals or cadavers). As much as 10 percent of the total air supplied to retort units is drawn through these charging doors.[19] Ash removal from retort units is accomplished manually with a rake and shovel at the completion of the incinerator cool-down period. Typical operation for a retort incinerator


Secondary Combustion Chamber
Charging Hopper
Rotary Kiln
Ash Discharge

Source: Reference 18

1081610R

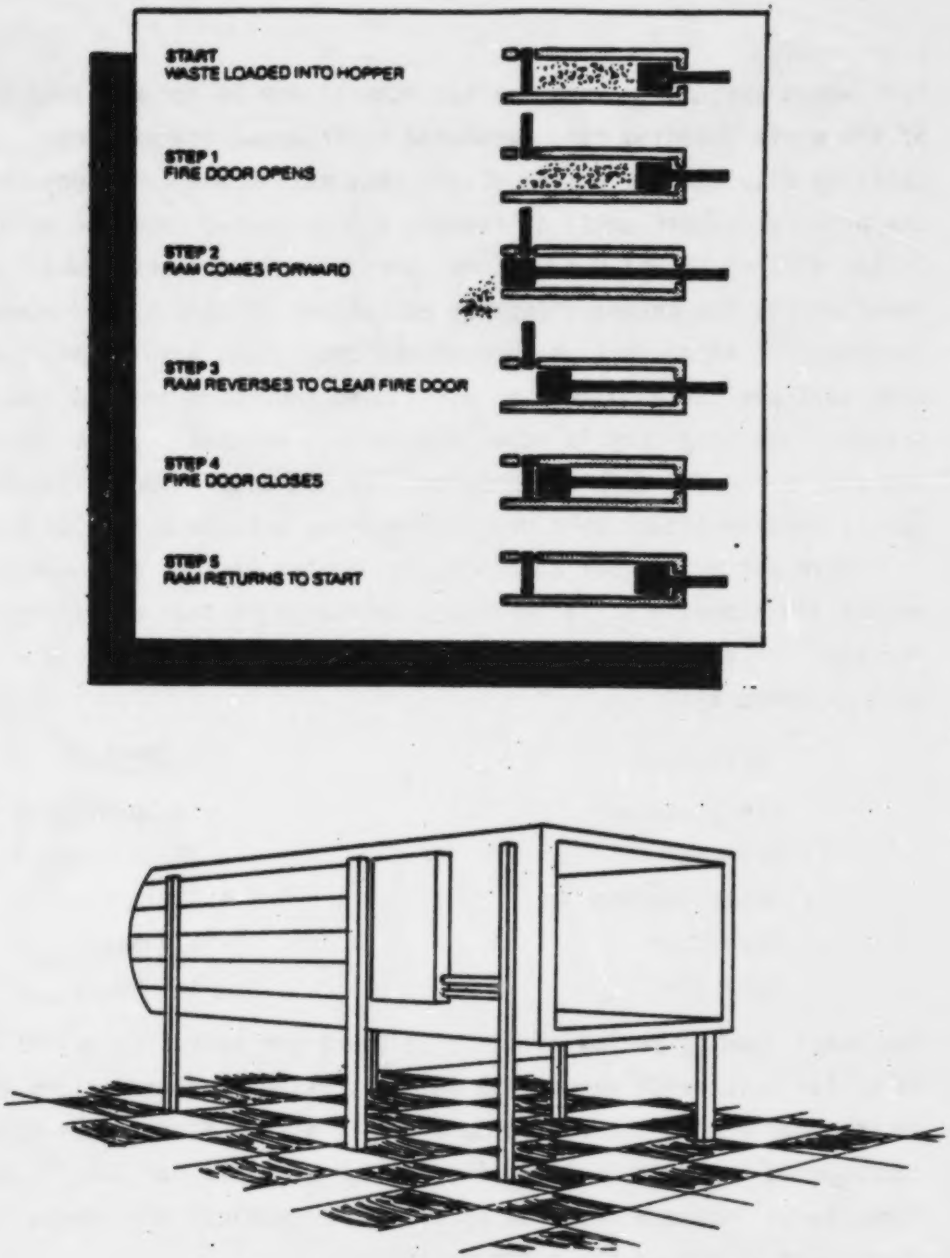
Figure 2-5. Refractory Rotary Kiln System

calls for incinerator heat up and waste charging at the end of the operating day, waste combustion and burnout by morning, and cool-down and ash cleanout during the following day.[20]

Controlled-air incinerators may be equipped with either manual or mechanical loading devices. For units with capacities less than 200 lb/hr, manual loading through a charging door in the primary chamber is typically the only option. Mechanical loaders, on the other hand, are standard features for incinerators with capacities above 500 lb/hr waste. For units between these size ranges, mechanical feed loaders are usually available as an option.[21] Most mechanical loader designs currently offered employ a hopper and ram assembly, as illustrated in Figure 2-6. In this system, waste is loaded into a charging hopper and the hopper cover is closed. The fire door isolating the hopper from the incinerator opens and a ram comes forward to push the waste into the front section of the incinerator. After reaching the end of its travel, the ram reverses and retracts to the point where it just clears the fire door. The fire door closes and the ram retracts to its starting position. These operations are normally controlled by an automatic control panel. For smaller incinerators, waste loading into the charging hopper is usually accomplished manually, bag by bag. Larger systems frequently use such waste loading devices as car dumpers, conveyors, skid-steer tractors, or pneumatic systems.[23]

In addition to improving personnel and fire safety, mechanical loaders limit the amount of ambient air which can leak into the incinerator during waste feeding operations. This is important for controlled air incinerators since excess air in-leakage can cause lower temperatures, incomplete combustion, and smoking at the stack. Mechanical loaders also permit the feeding of smaller waste batches at more frequent, regular intervals. As the intervals become shorter, this feeding procedure approximates continuous or steady-state operation and helps to dampen fluctuations in combustion conditions.[24]

Ash removal techniques for controlled air incinerators also range from manual to mechanical systems. For smaller units below about 500 lb/hr capacity (and units constructed before the mid-1970s), operators must rake and shovel ash from the primary combustion chamber into disposal containers.


START
WASTE LOADED INTO HOPPER
STEP 1
FIRE DOOR OPENS
STEP 2
RAM COMES FORWARD
STEP 3
RAM REVERSES TO CLEAR FIRE DOOR
STEP 4
FIRE DOOR CLOSES
STEP 5
RAM RETURNS TO START

Source: Reference 22

Figure 2-6. Schematic and Example of a Mechanical Loading System

For larger systems, mechanical ash removal may be accomplished by extension of the waste charging ram, augmented by internal transfer rams. The positive displacement action of the rams pushes the ash along the bottom of the primary chamber until it reaches a drop chute. Another mechanical system offered by one manufacturer uses a "pulsed hearth" whereby ash is moved across the chamber floor by pulsations created by end-mounted air cushions.[25] After falling through the drop chute, ash either falls into a drop cart positioned within an air-sealed enclosure or into a water quench trough. The drop cart is removed manually, generally after spraying the ash with water for dust suppression. In the water trough system, quenched ash is removed either by a drag conveyor or a backhoe trolley system.[26]

When estimating air emissions for controlled air incinerators with manual ash removal, it is important to recognize that operating, and hence emission, rates will vary over time. A typical operating cycle for such a unit is given by:[27]

Operation	Duration
Ash-clean-out	15-30 minutes
Preheat	15-60 minutes
Waste loading	12-14 hours
Burn-down	2-4 hours
Cool-down	5-8 hours

The waste loading period of 12 to 14 hours per operating day is a maximum value for units with manual ash removal; based on observations at one incinerator a more typical value might be 5 to 6 hours since this corresponds to waste incineration during one shift per day.[28] On the other hand, large incinerators with continuous mechanical ash removal systems may operate on an around-the-clock basis.

Since rotary kiln systems operate in a continuous mode, the waste feed system and ash removal system which service these incinerators must also be of a continuous or semi-continuous type.[29] A charging hopper and ram system is commonly used to load waste into the kiln. After travelling through the kiln, ash is discharged on a continuous basis either into an ash cart or water quench system. Both this feed system and ash removal system are described above for controlled air incinerators.

2.3 WASTE HEAT RECOVERY

Waste heat recovery operations are generally not considered for excess air incinerators due to the smaller gas flow rates, lower temperatures, higher particulate matter loadings, and intermittent operations that characterize these systems. For controlled air and rotary kiln incinerators, however, the relatively higher stack gas temperatures and flow rates can make heat recovery economically attractive in cases where steam or hot water generation rates can be matched with the needs of the hospital. For most systems, heat is recovered by passing hot gases through a waste heat boiler to generate steam or hot water. Boiler equipment can range from a spool piece with heat exchange coil inserted in the stack to a single-drum D-type watertube waste heat boiler. Most manufacturers, however, use conventional firetube boilers because they are low in cost and simple to operate.[30] Options for these boilers include supplemental firing of oil or natural gas and automatic soot-blowing systems. Outlet temperatures from waste heat boilers are generally limited to about 400°F by stack gas dew point considerations. As mentioned above, one manufacturer also offers a waterwall membrane in the primary chamber to enhance heat recovery.

Other methods to improve overall system efficiency in controlled air incinerators and, thereby, to reduce the need for expensive auxiliary fuels, are modulating burners and air preheating.[31] EPA-sponsored testing programs of controlled air incinerators equipped with these types of systems have shown that heat recovery efficiencies are typically limited to about 50 to 60 percent of the theoretical maximum.[32]

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3.0 AIR EMISSIONS/FACTORS FOR HOSPITAL WASTE INCINERATORS

Many sources of information were used to collect available hospital incinerator emissions data. A survey of pertinent literature was performed and contacts were made within EPA, State and local government organizations, trade organizations, and incinerator vendors.

Table 3-1 contains a list of pollutants covered by this study. The compounds shown here are those for which emissions data could be located for hospital incinerators. As expected, data for some pollutants were plentiful, while few data were found for others. One large data gap in the current hospital waste incinerator emissions data base is for lower molecular weight organic compounds. In addition, emission data located were primarily for larger, controlled air incinerators; few data were located for the smaller, retort-type incinerators which comprise a large portion of the existing population by number.

This section first contains brief descriptions of formation mechanisms for pollutants for which data were found. Where applicable, information on formation mechanisms for these compounds has been taken from the municipal solid waste (MSW) literature. Next, the emissions test data are presented along with other data which were located as part of the study. A discussion relating emissions data to design and operating factors follows. Finally, the emissions factors developed for each pollutant are presented.

3.1 FORMATION MECHANISMS

3.1.1 Acid Gases

The acid gases considered in this study were hydrogen chloride, sulfur dioxide, and nitrogen oxides.

3.1.1.1 Hydrogen Chloride. Based on thermodynamic considerations, chlorine which is chemically bound within the hospital waste in the form of polyvinyl chloride (PVC) or other compounds will be predominately converted to hydrogen chloride (HCl), assuming there is hydrogen available to react with the chlorine. However, the rate of HCl formation is inhibited and subsequently reversed when too much excess air is added to the combustion chambers.[1] Too much excess air can lower the combustion temperature by dilution and increase the oxygen content, thereby promoting greater free

TABLE 3-1. POLLUTANTS MEASURED/TESTED

Trace Metals	Polycyclic Organic Matter	Low Molecular Weight Organic Compounds	Acid Gases	Others
Arsenic	Dioxins	Ethane	Hydrochloric Acid	Particulate Matter
Cadmium	Furans	Ethylene	Sulfur Dioxide	Carbon Monoxide
Chromium		Propane	Nitrogen Oxides	Pathogens
Iron		Propylene		Viruses
Manganese		Trichlorotrifluoroethane		
Nickel		Trichloroethylene		
Lead		Tetrachloroethylene		

chlorine exhaust concentrations. Considering the high hydrogen content of hospital waste owing to its high paper, plastics, and moisture content, there should be a ready supply of hydrogen available in most cases to promote HCl formation.

Swedish studies have found that 60 to 65 percent of the fuel-bound chlorine in MSW is converted to HCl.[2] There is no apparent thermodynamic reason for the less than full conversion. HCl has also been shown by other studies to be the predominate chlorine product at high temperatures.[3]

3.1.1.2 Sulfur Dioxide. Sulfur, which is chemically bound within the materials making up hospital waste, is oxidized during the combustion process to form SO_2. The rate of SO_2 emissions is, therefore, directly proportional to the sulfur content of the waste. Some SO_2 removal may take place through reaction of the SO_2 with alkaline reagents also present within the waste; however, the amount of removal is expected to be negligible due to the high HCl content of the flue gas. Because it is a stronger acid than SO_2, HCl will react more quickly with available alkaline compounds than SO_2. The high HCl content of flue gases will likely tie-up the alkaline compounds before they have a chance to react with SO_2.

3.1.1.3 Nitrogen Oxides. Nitrogen oxides, or NO_x, represent the mixture of NO and NO_2. In combustion systems, predominantly NO is produced due to kinetic limitations in the oxidation of NO to NO_2. NO_x is formed by one of two general mechanisms. "Thermal NO_x" is the result of the reaction between molecular nitrogen and molecular oxygen, both of which enter the combustion zone in the combustion air. "Fuel NO_x" results from the oxidation of nitrogen which enters the combustion zone chemically bound within the waste material.

Although the detailed mechanism of thermal NO_x formation is not well understood, it is widely accepted that the thermal fixation in the combustion zone is described by the Zeldovich equations:[4]

$$N_2 + O \rightleftharpoons NO + N$$

$$N + O_2 \rightleftharpoons NO + O$$

The first reaction is the rate limiting step and is strongly endothermic due to the requirement of breaking the N_2 triple bond. It is the high endothermicity of this process which has led to the term "thermal NO_x." The reaction rates of these equations are highly dependent on both the mixture stoichiometric ratio (i.e., the molecular equivalent air-to-fuel ratio, with rich and lean describing the fuel amount) and the flame temperature. The maximum NO_x formation levels occur at slightly lean fuel mixture ratios due to the excess availability of oxygen for reaction within the hot flame zone. A rapid decrease in NO_x formation is seen for ratios which are slightly higher or lower than this. The rate of thermal NO_x formation is extremely sensitive to the flame temperature, dropping almost an order of magnitude with every 100°C drop in flame temperature.

The mechanisms by which nitrogen compounds (primarily organic) contained in liquid and solid fuels evolve and react to form NO_x are much more complex than the Zeldovich model, and the empirical data are less conclusive.

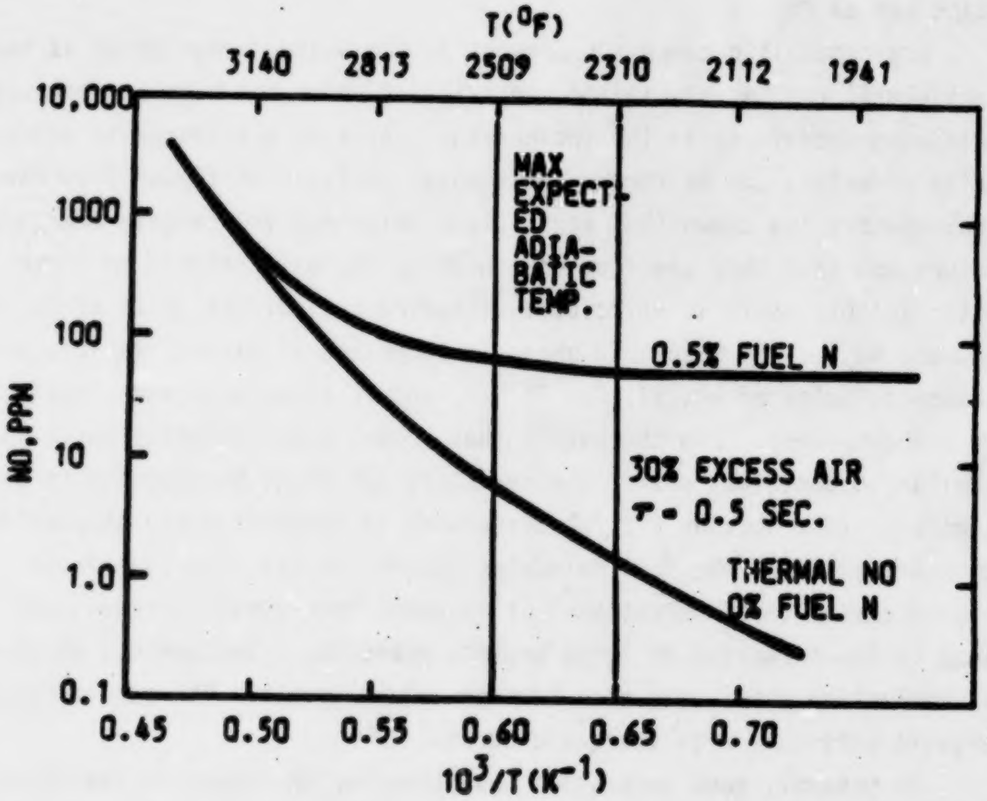
The impact of temperature and fuel nitrogen on NO_x emissions for excess air conditions is shown in Figure 3-1. The figure indicates that thermal NO_x formation is extremely sensitive to temperature, but fuel NO_x formation is less sensitive.

3.1.2 Particulate Matter

Particulate matter (PM) is emitted as a result of incomplete combustion and by the entrainment of noncombustibles in the flue gas stream. PM may exist as a solid or an aerosol, and may contain heavy metals or polycyclic organics. Depending on the method used to measure the PM in the flue gas, lower boiling point volatile compounds (i.e., boiling point below 100°C) may or may not be included in the measurement.

There are three general sources of PM[6]:

- inorganic substances contained in the waste feed that are carried into the flue gas from the combustion process,
- organometallic substances formed by the reactions of precursors in the waste feed, and
- uncombusted fuel molecules.



Source: Reference 5

Figure 3-1. Impact of Temperature and Fuel Nitrogen on NOx Emissions for Excess Air Conditions

Inorganic matter is not destroyed during combustion; most of this material leaves the incinerator as ash. Some, however, becomes entrained in the stack gas as PM.

Organometallic compounds present in the waste stream which is being incinerated can be volatilized and oxidized under the high temperatures and oxidizing conditions in the incinerator. As a result inorganic oxides or salts of metals can be formed. Elemental analysis of flyash from MSW incinerators has shown that particulate emissions are largely inorganic in nature and that they are from one-third to one-half soluble in water. The water soluble phase is principally chloride and sulfate salts of Na, P, Ca, Zn, and NH_4^+. The insoluble phase is comprised of oxides, silica, and phosphate salts of Al, Si, Ca, Pb, Zn, and Fe along with some insoluble carbon compounds.[7] To the extent that a particular hospital waste is similar to municipal waste, the resulting ash might be expected to be similar. (See Section 1.2 for discussion of hospital waste composition and categorization.) The fuel molecules themselves can also contribute significantly to PM formation. It is known that pyrolitic reactions can lead to the formation of large organic molecules. Inorganics, which may act as nucleation sites, may then further induce growth. The result can then be organic particles with inorganic cores.[8]

In general, good combustion conditions which depend on residence time, temperature, and turbulence, lead to lower PM emissions. As the residence time increases, particle size and the mass of PM tend to decrease. Smaller particle sizes and lower PM emissions are also associated with higher temperatures since, at higher temperatures, oxidation rates are increased so that more of the combustible PM is oxidized to gaseous products.

3.1.3 Trace Metals

The amount of trace metals in the flue gas is directly related to the quantity of trace metals contained in the incinerator waste. Some of the trace metal sources in the waste feed include surgical blades, foil wrappers, plastics, and printing inks. Plastic objects made of PVC contain cadmium heat stabilizing compounds. In addition, cadmium, chromium, and lead may also be found in inks and paints.

Some metals are selectively deposited on the smaller particulate sizes which are emitted. This is known as fine-particle enrichment. Although such data were not found for hospital incinerators, metals generally thought to exhibit fine-particle enrichment are As, Cd, Cr, Mn, Ni, Mo, Pb, Sb, Se, V, and Zn.[9] Results of one study performed at a MSW facility indicate that trace metals are found predominately in the respirable particulate fraction, even when the bulk of the particulate matter emissions are in the nonrespirable fraction.[10] Studies conducted by Trichon, et. al. have shown that certain metals when exposed to a reducing atmosphere can be converted to sub-oxides or even pure metal vapors. The end product of these overall reactions can result in particulate distributions less than 0.1 microns.[11]

There are three general factors affecting enrichment of trace metals on fine particulate matter[12]:

- particle size,
- number of particles, and
- flue gas temperatures.

The influence of particle size on trace metal enrichment of fine particles is thought to be due to specific surface area effects (i.e., the ratio of particle surface area to mass). Particles with large specific surface areas show more enrichment since there is more surface area for condensation per unit mass of PM. The influence of the number of particles is simply due to the increased probability of contact associated with higher particle population. There is some evidence that less enrichment occurs at higher flue gas temperatures.[13] Higher temperatures are thought to lead to increased activity levels which, in turn, make the metals less likely to condense and bond with PM.

Mercury, due to its high vapor pressure, does not show significant particle enrichment; rather it is thought to leave largely in the vapor form due to high typical exit gas temperatures. For example, the results of one study performed at a MSW facility indicated that less than 25 percent of the mercury emissions were found to be in the particulate phase of the stack gas.[14]

3.1.4 Organic Emissions

Figure 3-2 presents a schematic of the processes which are involved during hospital waste combustion in a two-stage incinerator. After startup,

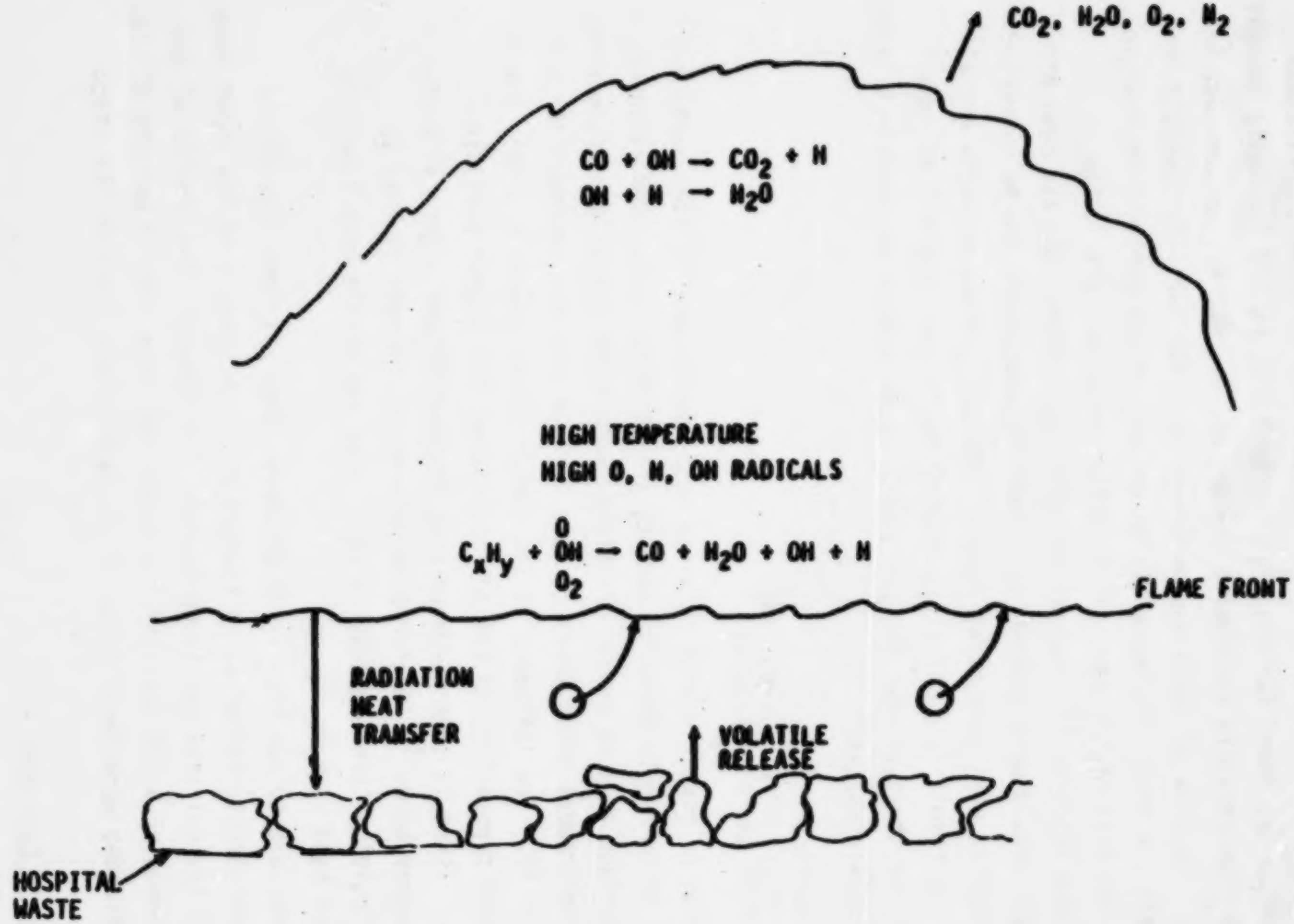

CO_2, H_2O, O_2, N_2
$CO + OH \rightarrow CO_2 + H$
$OH + H \rightarrow H_2O$
HIGH TEMPERATURE
HIGH O, H, OH RADICALS
$C_xH_y + \begin{matrix} O \\ OH \\ O_2 \end{matrix} \rightarrow CO + H_2O + OH + H$
FLAME FRONT
RADIATION HEAT TRANSFER
VOLATILE RELEASE
HOSPITAL WASTE

Figure 3-2. Process Schematic for Primary Chamber Hospital Waste Combustion

the hospital waste is heated by the burning gases being combusted in the primary chamber and by the natural gas or oil burner operating in that chamber. It is the burning of volatile matter above the waste bed which provides the heat which continues the pyrolysis and volatile matter evolution from the waste. The amount of radiant heat transfer to the waste is strongly dependent on the local flame temperature of the compounds being combusted; the flame temperature, in turn, is a function of moisture content, volatile matter heating value, and the local air stoichiometry. Not all the volatile matter is combusted in the primary chamber. Combustion gases are swept from the primary chamber to the secondary chamber where volatile matter combustion continues, augmented by the heat generated by a second fossil fuel burner.

The volatile matter combustion process is controlled by chemical kinetics and proceeds through complex reactions involving O, H, and OH radicals. The kinetics of these processes are strongly temperature dependent. An efficient burning process will result in a high degree of conversion of volatile organics to CO_2 and H_2O. Failure to achieve efficient combustion can result in high emission rates of unreacted or partially reacted organics.

Generally, insufficient combustion can occur as a result of charging the incinerator with waste materials in a batch mode. A study has shown that when waste materials are initially charged into the incinerator, the oxygen level in the incinerator is momentarily reduced, resulting in higher emission rates of unburned gaseous and particulate hydrocarbons.[15]

The unreacted or partially reacted combustion products discussed in this report include the chlorinated isomers of dibenzo-p-dioxin (CDD) and dibenzofuran (CDF), lower molecular weight organic compounds for which emissions data were available, and carbon monoxide (CO). A brief description of the formation mechanism and factors which influence the formation of these compounds is presented in the following subsections. Other important classes (e.g., PICs, BaP, PCBs, PAH, POM) are not included due to lack of emissions data.

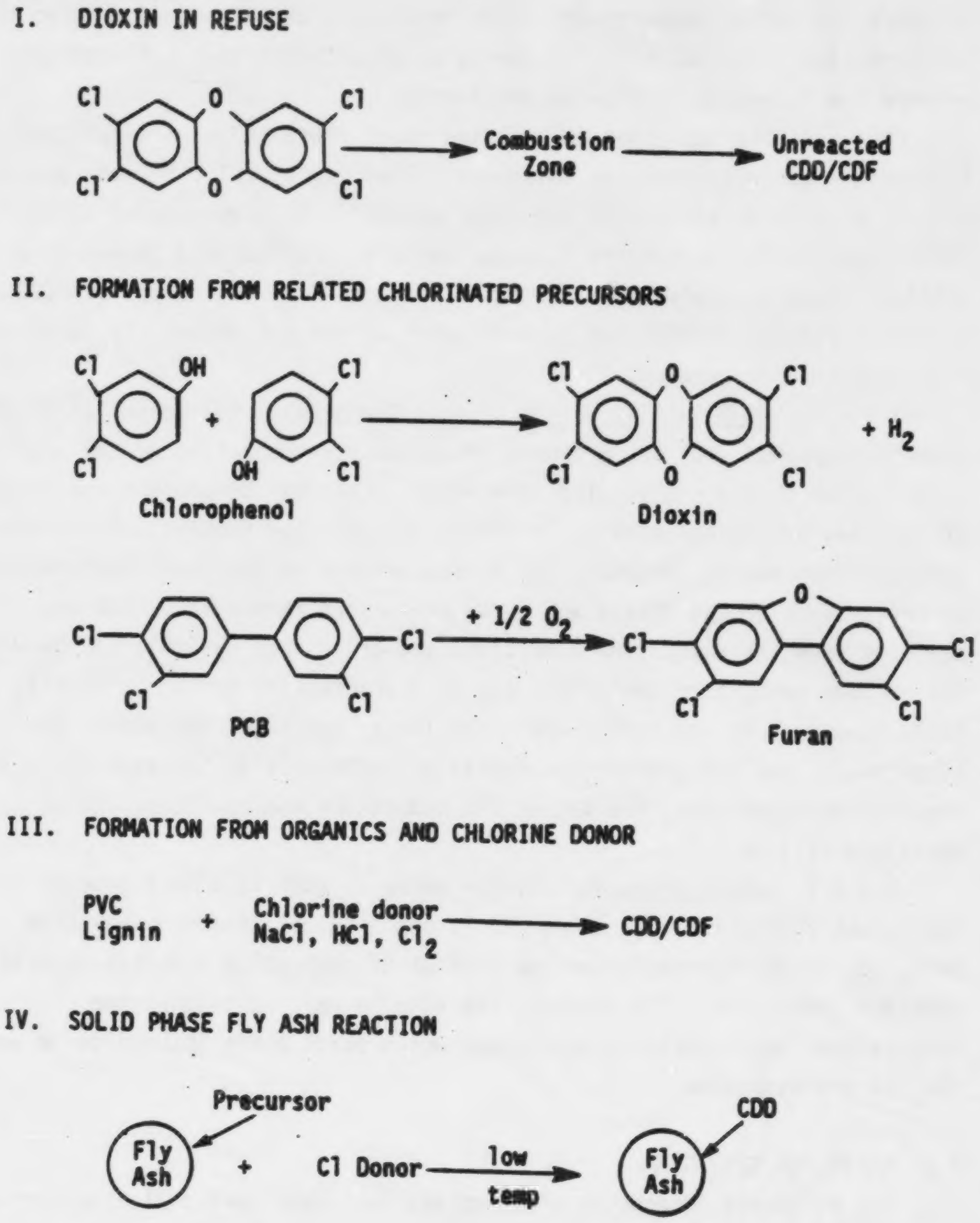
3.1.4.1 Dioxins and Furans. Many factors are believed to be involved in the formation of CDDs and CDFs and many different theories exist concerning their formation. The best supported theories are illustrated in Figure 3-3.[16] The first theory shown involves the breakthrough of unburned CDD/CDF present in the feed.[17] A few measurements of MSW feed streams have indicated the presence of trace quantities of CDD/CDF in the refuse feed. No such measurements have been made for hospital waste streams, but some potential for CDD/CDF in the feed may exist due to similarities in the wastes.

The second mechanism shown in Figure 3-3 involves the more plausible combination of precursor species which have structures similar to the dioxins and furans to form the CDD/CDF compounds. Such a reaction would involve the combination of chlorophenols or polychlorinated biphenyls to form CDD/CDF. These precursors can be produced by pyrolysis in oxygen-starved zones, such as those which exist in multichamber incinerators.[18] The potential for PVC-bearing wastes, a typical component of hospital waste, to form precursors during combustion has been studied by several researchers.[19,20]

The third mechanism shown in Figure 3-3 involves the synthesis of CDD/CDF from a variety of organics and a chlorine donor.[21] The simplest mechanisms here involve the combination of those species which are structurally related. Many plausible combustion intermediates can also be proposed which lead to precursors and eventually to CDD/CDFs. Analysis of intermediates formed during the combustion of complex fuels such as coal or wood indicate measureable yields of unchlorinated dioxin and furan species. These compounds could become chlorinated in systems such as hospital waste incinerators where high concentrations of molecular chlorine exist in the combustion zone.

The final mechanism presented in Figure 3-3 involves catalyzed reactions on fly ash particles at low temperatures. In research sponsored by the Ontario Ministry of Environment, formation of CDDs/CDFs were observed when the thermolysis products of PVC combusted in air were heated to 300°C in the presence of clean fly ash.[22]

There is a growing consensus that the formation of dioxins and furans in combustion furnaces requires excess air.[23] Excess air combustion leads


I. DIOXIN IN REFUSE
Cl
O
Cl
Cl
O
Cl
Combustion Zone
Unreacted CDD/CDF
II. FORMATION FROM RELATED CHLORINATED PRECURSORS
Cl
OH
+
Cl
Cl
OH
Cl
Chlorophenol
Cl
O
Cl
Cl
O
Cl
+ H2
Dioxin
Cl
Cl
+ 1/2 O2
Cl
Cl
PCB
O
Cl
Cl
Cl
Cl
Furan
III. FORMATION FROM ORGANICS AND CHLORINE DONOR
PVC
Lignin
+
Chlorine donor
NaCl, HCl, Cl2
CDD/CDF
IV. SOLID PHASE FLY ASH REACTION
Precursor
Fly Ash
+
Cl Donor
low
temp
CDD
Fly Ash

Source: Reference 16

Figure 3-3. Hypothetical Mechanisms of CDD/CDF Formation Chemistry

to lower combustion temperatures which favor in-situ chlorine formation over HCl formation. The additional presence of chlorine is then believed to promote the formation of dioxins and furans.

CDDs and CDFs may exist in both the vapor phase and as fine particulate in hospital waste incinerator emissions. They may be split between phases with as much as 80 percent in the vapor phase.[24] At temperatures below 300°F, they condense onto the fine particulate. Furthermore, based on a national study of combustion sources, a range of 0.05 to 135 ppb of PCDD and 0.07 to 3,734 ppb of PCDF has been detected in the bottom and fly ashes of four hospital incinerators.[25]

3.1.4.2 Low Molecular Weight Organic Compounds. Low molecular weight organic compounds (LC) are products of incomplete combustion of the volatiles which are evolved from the waste. They may be present due to some of the same mechanisms previously discussed above for dioxins and furans; that is, they may be compounds which were present in the fuel, combinations of precursors, or the dioxin and furan precursors themselves. LCs are produced when the combustion conditions are other than optimal. In general, the optimum combustion conditions can be characterized by the three T's; time, temperature, and turbulence. The longer the time, the higher the temperature, and the greater the degree of turbulence in the zone where the organics are combusted, the better the combustion and the lower the LC emissions will be.

3.1.4.3 Carbon Monoxide. Carbon monoxide (CO) is also a product of incomplete combustion. As shown, CO is one chemical reaction away from being CO_2 which represents the end product of combustion and this signifies complete combustion. Its presence can also be related to the time, temperature, and turbulence conditions which exist above the region in which the LCs are vaporized.

3.2 EMISSIONS TEST DATA

Two different categories of emissions test data were collected during this study: 1) data which had been reviewed and were considered final and 2) preliminary data which had not received final review and inspection. Both categories of data are reported in this section for the sake of completeness but only the final data are used to calculate typical emission factors. Final emissions data were acquired from seven comprehensive emissions tests of hospital incineration units.[26-29,40-42] In addition, results of several less detailed tests at hospital incinerator units were located through the literature. A description of each of the seven units for which comprehensive information was obtained and the operating conditions recorded during the emissions tests are presented in Table 3-2. As shown, most of the units are large incinerators near the upper end of the size range for hospital incinerators. The smallest unit for which comprehensive test results were located is an 175 lb/hour unit and the largest was a 2000 lb/hr unit. Over the period of the comprehensive emissions tests, four of the units operated at 82 to 99 percent of feed rate design capacity. The remaining three incinerator feed rates ranged from 396 to 1,493 lb/hr during the test; maximum design capacities for these incinerators are not known.

All of the units shown in Table 3-2 are starved air incinerators with two combustion chambers. The operating temperature of the secondary combustion chamber is slightly lower for the Illinois hospital incinerator than for the other units. It should be noted that the secondary chamber temperature data for the Illinois incinerator include both start-up and shutdown periods. Thus, the lower end of this range most likely corresponds to these transient operating conditions. Three of the test reports did not include incinerator design specifications.

The stack parameters for all of the units are within what was determined to be the normal design range (see Section 6.0). Unfortunately, little information is available regarding the operating conditions of the Illinois, Queen of the Valley, Swedish-American, and University of Michigan units. No information was available regarding the characteristics of the hospital wastes which were incinerated by any of these units. In addition, sufficient flue gas composition data were not available to normalize emission values to a single O_2 or CO_2 level.

No emissions data were located for the smaller retort-type incinerators which comprise a large portion of the total population by number. It is important to remember that the emission data and factors discussed in this

TABLE 3-2. TEST SITE DESIGN AND OPERATING PARAMETERS FOR COMPREHENSIVE EMISSION TEST

	Cedar Sinai[a] Medical Center Los Angeles, CA	St. Agnes[b] Medical Center Fresno, CA	Royal Jubilee[c] Hospital Victoria, BC	Illinois[d] Hospital Test
Incinerator Mfg.	Ecolaire	Ecolaire	Consumat	N/A
Model #	1,500 TES	1,000 TE	C-760	N/A
Design Feed Rate (lb/hr)	1,200	800	2,200	N/A
Actual Feed Rate (lb/hr)	980	783	1,930	500-800
Incinerator Load (%)	82	98	88	N/A
Operating Temperature (^oF):				
Primary Chamber	1,600-1,800	1,500-1,600	1,400	1,350-1,900
Secondary Chamber	1,800-2,000	1,800-2,000	1,700	1,200-1,950
Stack Parameters:				
Temperature (^oF)	332	238	312	390-500
Flowrate (dscfm)	2,710	2,766	7,000	N/A
Velocity (ft/s)	43	34.7	37.9	N/A
Diameter (in.)	18	19	29	N/A
Moisture (vol %)	9.3	9.6	6.4	N/A
No. of Tests	3	3	8	-

[a] Reference 26.

[b] Reference 27.

[c] Reference 28.

[d] Reference 29.

TABLE 3-2. TEST SITE DESIGN AND OPERATING PARAMETERS FOR DETAILED TESTS
(Continued)

	Queen of the[e] Valley Hospital Napa, CA	Swedish-American[f] Hospital Rockford, IL	University of[g] Michigan Hospital Ann Arbor, MI
Incinerator Mfg.	NR	Consumat	Basic Environmental Engineering
Model #	NR	C-75-P	1500
Design Feed Rate (lb/hr)	NR	175	NR
Actual Feed Rate (lb/hr)	Avg = 396	174	1493
Incinerator Load (%)	NR	99%	NR
Operating Temperature (°F):			
Primary Chamber	NR	NR	NR
Secondary Chamber	NR	NR	1800
Stack Parameter:			
Temperature (°F)	275	601	385
Flowrate (DSCFM)	760	1170	6333
Velocity (ft/s)	16.0	16.9	38
Diameter (in.)	15	21	30
Moisture (vol %)	10.2	6	10
No. of Tests	3	5	3

[e] Reference 40.

[f] Reference 41.

[g] Reference 42.

section are based on the performance of relatively large controlled air incinerators. More data are needed to accurately characterize emissions from smaller, retort incinerators.

3.2.1 Acid Gases

Hydrogen Chloride. Table 3-3 contains a summary of the hydrogen chloride (HCl) emissions data which were gathered during this study. Emissions factors are also shown for each of the units. The HCl emissions results of Table 3-3 include the units described in Table 3-2 as well as units in the United States and Canada for which information was obtained from a survey article.[30] There is no apparent correlation between the unit feed rates and the HCl emissions. This is understandable because, as previously stated, the level of HCl emissions should be directly related to the percentage of chlorine-containing compounds in the waste fed to the unit. Unfortunately, no information was given regarding the chemical composition of the wastes being burned.

Two of the units for which emissions data are available have scrubbers which are used for acid gas control. These units have the lowest emissions rates of those shown. The type of wet scrubbers used was not identified in Reference 30.

Sulfur Dioxide and Nitrogen Oxides. Table 3-4 summarizes the emissions data and calculated emission factors for SO_2 and NO_x. As can be seen, there are limited data available for these compounds. The only two sources found were two test reports from the state of California.

On a concentration basis, the emission rates for the pollutants in Table 3-4 are relatively low. For the highest SO_2 concentration, 50 ppmv, an equivalent SO_2 emissions rate of 0.15 lb/million Btu would be expected, assuming a mean heat content of 10,000 Btu/lb for hospital waste. A mean heating value of 5,000 Btu/lb would correspond to an SO_2 emissions rate of 0.3 lb/million Btu. The corresponding maximum NO_x emissions rates (based on the 270 ppmv concentration) are 0.4 and 0.8 lb/million Btu for heat contents of 10,000 and 5,000 Btu/lb, respectively.

3.2.2 Particulate Matter

A great deal of PM emissions data have been collected for controlled air hospital waste incinerators. Some of the most readily available data are shown in Table 3-5. Much of this data has been collected because

TABLE 3-3. DATA/FACTORS FOR HYDROGEN CHLORIDE EMISSIONS FROM HOSPITAL WASTE INCINERATORS

Hospital	Add On Control Device/ Heat Recovery	Incinerator Feed Rate (lb/hr)	HCl Concentration (ppmv)	Emissions Factor (lb/ton feed)
Cedar Sinai[a]	Fabric Filter/Yes	980		
High			521.0	16.3
Low			403.0	12.7
Average			462.0	14.5
St. Agnes[b]	None	783		
High			926.0	15.5
Low			764.0	12.0
Average			845.0	13.7
Royal Jubilee[c]	None	1,930		
High			1,520.0	65.7
Low			983.0	42.5
Average			1,252.0	54.1
Illinois Unit[d]	None	500-800		
High			1,490.0	10.6[e]
Low			170.0	6.6[e]
Average			550.0	8.6[e]
Queen of the Valley[h]	NR			
High		412	445	8.7
Low		374	282	6.4
Average		396	341	7.2
Swedish-American[i]	NR			
High		175	174	12
Low		172	172	12.9
Average		174	173	12.5
University of Michigan[j]	NR			
High		1493	928	45.4
Low			644	31.1
Average			788	87.8

TABLE 3-3. DATA/FACTORS FOR HYDROGEN CHLORIDE EMISSIONS FROM HOSPITAL WASTE INCINERATORS (CONTINUED)

Hospital	Add On Control Device/ Heat Recovery	Incinerator Feed Rate (lb/hr)	HCl Concentration (ppmv)	Emissions Factor (lb/ton feed)
Athabasca[f]	None	85	41.0	68.1
Misericordia[f]	None	740	670.0	63.1
Misericordia[f]	None	740	687.3	63.1
Royal Alex[f]	None/Yes	1,160	553.0	84.5
Royal Alex[f]	None/Yes	1,200	562.0	79.6
Foothills[f]	None	2,500	702.0	72.8
Lethbridge Gen.[f]	Wet Scrubber/Yes	1,060	44.6	5.9[g]
Univ. of Alberta[f]	Wet Scrubber/Yes	1,400	64.7	0.7[g]
Univ. of Alberta[f]	Wet Scrubber/Yes	1,400	25.4	4.4[g]
Bonnyville[f]	None	130	62.2	16.5
Willingdon[f]	None	130	308.0	24.3
Lacombe[f]	None	150	234.5	14.6
Ft. McMurray[f]	None	265	700.0	48.6
Ontario Hospitals[k]	None	408	NR	17.4
St. Michaels[k]	None	465	2,095.0	99.4
Queen Elizabeth II[k]	None	575	115.0	22.3
Queen Elizabeth II[k]	None	700	287.0	19.1
Queen Elizabeth II[k]	None	700	378.0	25.3

TABLE 3-3. DATA/FACTORS FOR HYDROGEN CHLORIDE EMISSIONS FROM HOSPITAL WASTE INCINERATORS (CONTINUED)

Hospital	Add On Control Device/ Heat Recovery	Incinerator Feed Rate (lb/hr)	HCl Concentration (ppmv)	Emissions Factor (lb/ton feed)
Mediwaste[l]	None	1,200	NR	9.5
Shore Memorial[m]	None	650	NR	9.2
Nyack Hospital[n]	None	NR	NR	2.9

[a] Reference 26.

[b] Reference 27.

[c] Reference 28.

[d] Reference 29.

[e] Based on emissions factors presented in Reference 29.

[f] Reference 30.

[g] Wet scrubber may have reduced HCl emisssions.

[h] Reference 40.

[i] Reference 41.

[j] Reference 42.

[k] Reference 43.

[l] Reference 46.

[m] Reference 47.

[n] Reference 48.

NR - Not Recorded

TABLE 3-4. DATA/FACTORS FOR SO_2 AND NO_x EMISSIONS FROM HOSPITAL WASTE INCINERATORS

	Cedar Sinai[a] Medical Center Los Angeles, CA		St. Agnes[b] Medical Center Fresno, CA		Emissions Factor
Pollutant	(ppmv)	(lb/ton feed)	(ppmv)	(lb/ton feed)	(lb/ton feed)
Sulfur Dioxide					
High	50	3.01	20	1.54	3.01
Low	25	1.51	19	1.47	1.47
Average	37	2.22	19	1.47	1.85
Nitrogen Oxides					
High	270	7.82	155	5.75	7.82
Low	160	4.64	155	5.75	4.64
Average	217	6.29	155	5.75	6.02

[a] Reference 26.
[b] Reference 27.

TABLE 3-5. DATA/FACTORS FOR PARTICULATE EMISSIONS FROM HOSPITAL WASTE INCINERATORS[m]

Hospital	Add-On Control Device/ Heat Recovery	Incinerator Feed Rate (lb/hr)	Particulate Loading (gr/dscf)	Emissions Factor (lb/ton feed)
Cedar Sinai[a]	Fabric Filter/Yes	980		
High			0.002	0.10
Low			0.001	0.05
Average			0.001	0.07
Swedish-American[i]	NR			
High		175	0.209[g]	2.39
Low		172	0.050[g]	0.57
Average		174	0.127[g]	1.45
Queen of the Valley[h]	NR			
High		412	0.105	1.4
Low		374	0.073	0.85
Average		396	0.084	1.1
St. Agnes[b]	None/Yes	783		
High			0.090	5.45
Low			0.080	4.84
Average			0.080	5.15
Illinois Unit[d]	None/No	500-800		
High			0.170	3.20[e]
Low			0.020	2.00[e]
Average			0.040	2.60[e]
University of Michigan[j]	NR			
High			0.0468	3.42
Low			0.0382	2.77
Average		1493	0.0438	3.16
Royal Jubilee[c]	None/No	1930		
High			0.028	1.82
Low			0.022	1.37
Average			0.025	1.60
Athabasca[f]	None/No	85	0.050	26.92
Willingdon	None/No	130	0.070	1.69
Bonnyville	None/No	130	0.080	11.85

TABLE 3-5. DATA/FACTORS FOR PARTICULATE EMISSIONS FROM HOSPITAL WASTE INCINERATORS[m] (CONTINUED)

Hospital	Add-On Control Device/ Heat Recovery	Incinerator Feed Rate (lb/hr)	Particulate Loading (gr/dscf)	Emissions Factor (lb/ton feed)
Lacombe	None/No	150	0.070	5.87
Ft. McMurray	None/No	265	0.050	13.28
W.C. McKen.	None/No	275	0.020	3.20
Red Deer	None/Yes	410	0.080	36.49
St. Michaels	None/No	465	0.080	1.70
Queen Elizabeth II	None/No	575	0.030	6.12
Queen Elizabeth II	None/No	700	0.030	2.70
Misericordia	None/No	740	0.060	2.97
Misericordia	None/No	740	0.100	4.76
Northwest Medical Center	None	1,015	0.22[g]	6.7
Royal Alex	None/Yes	1,160	0.030	3.41
Royal Alex	None/Yes	1,200	0.070	3.30
Foothills	None/No	2,500	0.060	1.76
Lethbridge Gen.	Wet Scrubber/Yes	1,060	0.040	2.12
Univ. of Alberta	Wet Scrubber/Yes	1,400	0.020	1.23
North Erlanger[l]	NR			
High			0.0752	
Low			0.0434	
Average			0.0565	
South Erlanger[l]	NR			
High			0.0913	
Low			0.0536	
Average			0.0743	

TABLE 3-5. DATA/FACTORS FOR PARTICULATE EMISSIONS FROM HOSPITAL WASTE INCINERATORS[m] (CONTINUED)

Hospital	Add-On Control Device/ Heat Recovery	Incinerator Feed Rate (lb/hr)	Particulate Loading (gr/dscf)	Emissions Factor (lb/ton feed)
Mediwaste[n]	None	1,200	0.08	5.6
Shore Memorial[o]	None	600	0.06	1.5
Nyack Hospital[p]	None	NR	0.16	1.5

[a] Reference 26.

[b] Reference 27.

[c] Reference 28.

[d] Reference 29.

[e] Based on emissions factors presented in Reference 29.

[f] All of the information from Athabasca to Univ. of Alberta are from Reference 30.

[g] Corrected to 12 percent CO_2

[h] Reference 40.

[i] Reference 41.

[j] Reference 42.

[k] Reference 44.

[l] Reference 45.

[m] All the incinerators identified in this table were two-stage controlled air units. The University of Alberta unit had a rotating hearth for a primary chamber; all other units had a fixed primary chamber.

[n] Reference 46.

[o] Reference 47.

[p] Reference 48.

several states require hospital incineration units to meet PM emission limits. Therefore, testing is carried out on a routine basis. In addition, as previously stated, vendors frequently offer guarantees regarding PM emissions.

The PM emission results in Table 3-5 include the results of the comprehensive emissions tests (the first four hospitals) and test results obtained from the survey article.[31] These units are the same units for which HCl data were presented. The data shown from the survey article are arranged in order of ascending feed rate to show any effect of unit size on PM emissions. The emission factors in Table 3-5 show no clear trend between specific PM emission rates and unit size. It is interesting to note that the highest emission factors (above 10 lb/ton feed) are associated with the smaller units (below 400 lb/hr). Based on the information in Section 2.1, these units may well be retort-type incinerators. Unfortunately, no design information is available to confirm this hypothesis.

Emissions results for units operating with PM control equipment are also shown in Table 3-5. The Cedar Sinai unit, which was installed with a fabric filter for PM control, had the lowest PM emissions factor of those presented. The control efficiency for the filter was 98 percent. The other two units which had PM control equipment are the Lethbridge General and University of Alberta units. The emissions factors for these two units are considerably higher and are not markedly different from incinerators operated without PM control equipment. Both wet scrubber systems for Lethbridge General and the University of Alberta are designed and operated for acid gas control and not for PM removal. In general, wet scrubbers designed for acid gas removal operate at low gas-side pressure drops for purposes of low energy consumption. High energy and high gas-side pressure drops are required to obtain high efficiencies for PM control. Unfortunately, no inlet data were given for these units, so the control efficiencies could not be determined.

3.2.3 Trace Metals

Table 3-6 contains a summary of the available trace metal emission data for hospital waste incinerators. An emissions factor based on the waste feed rate to the unit is also given for each of the emissions rates

TABLE 3-6. DATA/FACTORS FOR TRACE ELEMENT EMISSIONS FROM HOSPITAL WASTE INCINERATORS

	PM Device	As		Cd		Cr		Fe		Mn		Ni		Pb	
		gr/dscf (x10^{-6})	lb/ton (x10^{-4})	gr/dscf (x10^{-6})	lb/ton (x10^{-4})	gr/dscf (x10^{-6})	lb/ton (x10^{-4})	gr/dscf (x10^{-6})	lb/ton (x10^{-4})	gr/dscf (x10^{-6})	lb/ton (x10^{-4})	gr/dscf (x10^{-6})	lb/ton (x10^{-4})	gr/dscf (x10^{-6})	lb/ton (x10^{-4})
Cedar Sinai[a,d]															
High	Y	0.00086	0.00041	0.103	0.053	0.069	0.032	0.516	0.245	0.112	0.053	0.643	0.304	2.15	1.02
Low	Y	0.00079	0.00037	0.112	0.050	0.016	0.008	0.474	0.227	0.103	0.051	0.593	0.214	1.98	0.94
Average	Y	0.00084	0.00039	0.109	0.051	0.046	0.021	0.502	0.238	0.109	0.051	0.628	0.267	2.09	0.99
High	N	5.99	2.92	140	68.0	7.46	3.63	153	72.6	9.23	4.37	2.34	1.12	1190	580
Low	N	3.02	1.47	59	29.0	2.15	1.02	85	41.2	6.74	3.29	2.22	1.08	620	304
Average	N	4.30	2.08	92	44.4	4.09	1.98	65	55.3	8.30	1.96	2.28	1.10	896	434
St. Agnes[b,d]															
High	N	4	2.14	67	40.9	11	6.07	166	101.6	7	3.93	5	2.80	916	559
Low	N	1	0.71	46	24.8	5	2.88	68	39.8	3	1.58	3	1.58	532	310
Average	N	2	1.19	55	31.9	8	4.69	130	75.1	5	2.88	4	2.38	749	433
Royal Jubilee[c,d]															
High	N	N/A	N/A	52.4	33.2	30.9	19.5	292	183	18.1	11.4	8.0	5.0	686	434
Low	N	N/A	N/A	24.7	15.5	16.3	10.2	284	180	12.3	7.8	5.8	3.6	638	399
Average	N	N/A	N/A	38.6	24.4	23.6	14.9	238	182	15.2	9.6	6.9	4.3	662	417
Overall Uncontrolled[d]															
High	N	--	2.92	--	68.0	--	19.5	--	183	--	11.4	--	5.0	--	580
Low	N	--	0.71	--	15.5	--	1.02	--	39.8	--	1.58	--	1.08	--	304
Average	N	--	1.81	--	35.2	--	7.22	--	103	--	5.40	--	2.53	--	371

[a] Reference 26.

[b] Reference 27.

[c] Reference 28.

[d] High and low values are results of individual test runs.

presented. In addition, for the Cedar Sinai unit, results for upstream and downstream of the fabric filter are presented.

No additional trace metals data were identified by the study. Because two of the reports are from California, a state recently beginning to require testing, it can be assumed that future tests will be a source for additional data.

Analysis of the Cedar Sinai data indicate that there is a substantial reduction in trace element emissions across the fabric filter. No apparent trends in the data were observed relating trace metal concentration to incinerator size.

3.2.4 Organic Emissions

Tables 3-7 and 3-8 contain summaries of the available emissions data for CDD and CDF compounds from hospital incinerators. An emissions factor based on waste feed rate to the unit is also given for each of the concentration value presented. The homolog emission data from three emissions tests are shown. Limited isomer emission data were available for the Cedar Sinai and St. Agnes tests. For the Cedar Sinai unit results from both upstream and downstream of the fabric filter are presented.

At this time, these are the only finalized CDD and CDF emissions test results for hospital incinerator units which have been reported. An additional unit located at Stanford University Medical Center in California was also recently tested for CDDs and CDFs.[32] The results of this test were not available as of the writing of this report. The California Air Resource Board (CARB) has recently begun to require testing for CDDs and CDFs at newly installed hospital incinerators, so additional data will be available through CARB in the future.

Analysis of the emissions data presented for the unit at Cedar Sinai indicates that for most of the dioxin and furan homologs, a slight reduction occurs across the fabric filter. The subgroups for which this reduction was not seen are the TCDD and TCDF homologs. Ash analyses for the Cedar Sinai incinerator are presented in Table 3-9.

No statements can be made relative to trends in the data related to unit size or operating characteristics because too little is known about the operation of each of the facilities during testing.

TABLE 3-7. DATA/FACTORS FOR CHLORINATED DIBENZO-P-DIOXINS EMISSIONS FROM HOSPITAL WASTE INCINERATORS

	Cedar Sinai[a,d] Medical Center Los Angeles, CA (Fabric Filter)		Cedar Sinai Medical Center Los Angeles, CA (Uncontrolled)		St. Agnes[b,d] Medical Center Fresno, CA (Uncontrolled)		Royal Jubilee[c,d] Hospital Victoria, BC (Uncontrolled)		Emissions Factor (Uncontrolled)
	(ng/nM^3)	(lb/ton feed) ($x10^{-6}$)	(ng/nM^3)	(lb/ton feed) ($x10^{-6}$)	(ng/nM^3)	(lb/ton feed) ($x10^{-6}$)	(ng/nM^3)	(lb/ton feed) ($x10^{-6}$)	(lb/ton feed) ($x10^{-6}$)
(Tetra) TCDD									
High	6.09	0.13	6.7	0.13	38.5	1.07	ND	ND	1.07
Low	5.85	0.12	2.1	0.04	3.3	0.09	ND	ND	0.04
Average	5.97	0.12	4.3	0.08	20.9	0.58	ND	ND	0.33
(Penta) PeCDD									
High	18.30	0.38	16.2	0.32	23.5	0.66	28.6	0.76	0.76
Low	14.50	0.30	11.0	0.20	18.2	0.48	4.1	0.11	0.11
Average	16.40	0.34	12.9	0.24	20.9	0.57	10.2	0.42	0.41
(Hexa) HxCDD									
High	27.40	0.57	36.3	0.71	54.4	1.52	9.7	0.52	1.52
Low	20.40	0.42	24.7	0.45	38.7	1.02	19.2	0.27	0.27
Average	23.90	0.49	31.9	0.60	46.6	1.27	13.8	0.37	0.75
(Hepta) HpCDD									
High	51.10	1.05	94.8	1.76	137.0	3.83	19.2	0.50	3.83
Low	49.40	1.02	62.1	1.14	85.5	2.25	11.4	0.32	0.32
Average	50.25	1.04	77.2	1.45	111.3	3.04	16.7	0.45	1.65
(Octa) OCDD									
High	39.20	0.81	114.0	2.12	196.0	5.47	26.7	0.74	5.47
Low	26.50	0.55	62.5	1.15	145.0	3.81	12.4	0.34	0.34
Average	32.85	0.68	83.8	1.58	170.5	4.64	22.8	0.61	2.28
Total PCDD									
High	130.00	2.69	259.0	4.82	450.0	12.52	83.5	2.23	12.52
Low	129.00	2.67	163.0	2.99	290.0	7.64	51.8	1.43	1.43
Average	129.50	2.68	210.3	3.96	370.0	10.08	68.9	1.85	5.30

[a] Reference 26.
[b] Reference 27.
[c] Reference 28.
[d] High and low values are results of individual test runs.

TABLE 3-8. DATA/FACTORS FOR CHLORINATED DIBENZOFURANS EMISSIONS FROM HOSPITAL WASTE INCINERATORS

	Cedar Sinai[a,d] Medical Center Los Angeles, CA (Fabric Filter)		Cedar Sinai Medical Center Los Angeles, CA (Uncontrolled)		St. Agnes[b,d] Medical Center Fresno, CA (Uncontrolled)		Royal Jubilee[c,d] Hospital Victoria, BC (Uncontrolled)		Emissions Factor (Uncontrolled)
	(ng/nM^3)	(lb/ton feed) ($x10^{-6}$)	(ng/nM^3)	(lb/ton feed) ($x10^{-6}$)	(ng/nM^3)	(lb/ton feed) ($x10^{-6}$)	(ng/nM^3)	(lb/ton feed) ($x10^{-6}$)	(lb/ton feed) ($x10^{-6}$)
(Tetra) TCDF									
High	67.10	1.38	79.8	1.55	78.7	2.07	34.9	0.93	2.07
Low	56.50	1.17	35.5	0.65	64.9	1.81	18.9	0.50	0.50
Average	61.80	1.28	59.2	1.12	71.8	1.94	27.0	0.73	1.26
(Penta) PeCDF									
High	103.00	2.12	106.0	2.06	136.0	3.79	53.1	1.45	3.79
Low	80.40	1.67	68.9	1.91	130.0	3.42	48.3	0.90	0.90
Average	91.70	1.89	92.6	1.74	133.0	3.61	46.2	1.24	2.20
(Hexa) HxCDF									
High	118.00	2.44	163.0	3.03	202.0	5.63	57.5	1.51	5.63
Low	90.90	1.88	116.0	2.12	170.0	4.46	29.8	0.82	0.82
Average	104.45	2.16	144.0	2.71	186.0	5.04	42.9	1.15	2.97
(Hepta) HpCDF									
High	110.00	2.27	204.0	3.79	232.0	6.46	35.4	0.96	6.46
Low	109.00	2.25	152.0	2.82	160.0	4.19	20.8	0.55	0.55
Average	109.50	2.26	169.7	3.19	196.0	5.33	25.7	0.70	3.07
(Octa) OCDF									
High	49.10	1.02	163.0	3.03	166.0	4.35	27.7	0.75	4.35
Low	38.00	0.78	67.7	1.24	150.0	4.19	7.7	0.21	0.21
Average	43.55	0.90	105.1	1.97	158.0	4.27	13.8	0.37	2.21
Total PCDF									
High	435.00	8.98	695.0	10.74	785.0	21.87	196.5	5.36	21.87
Low	106.00	8.01	441.0	8.09	704.0	18.51	117.3	3.25	3.25
Average	270.50	8.50	570.7	10.74	744.5	20.19	155.6	4.19	11.71

[a] Reference 26.
[b] Reference 27.
[c] Reference 28.
[d] High and low values are results of individual test runs.

TABLE 3-9. FABRIC FILTER DIOXIN/FURAN ASH ANALYSIS FOR CEDAR SINAI INCINERATOR[a]

	Loadings (ng/g)
Dioxins	
Tetra	1.6
Penta	3.7
Hexa	8.9
Hepta	33.6
Octa	65.7
Total PCDD	114.0
Furans	
Tetra	13.6
Penta	19.0
Hexa	22.6
Hepta	42.2
Octa	43.5
Total PCDF	141.0

[a] Reference 26.

Table 3-10 contains emissions factors for the low molecular weight organics for which emissions results were identified. These factors were determined from information collected at three of the comprehensive test sites.

3.2.5 Carbon Monoxide

The CO emissions data which were identified during this study are presented in Table 3-11. Also presented are the hydrocarbon (HC) data which were found. It should be noted that the HC data are reported as propane. The CO concentrations measured were below the detection limit of 50 ppmv and are, therefore, reported as less than 50 ppmv for two of the three incinerators tested. The concentration of CO from the Swedish-American incinerator was reported at 9.5 ppmv.

A comparison of the HC emissions factors of Table 3-11 to the LC factors of Table 3-10 suggests that only a small portion of the total HC reported in Table 3-11 is comprised of the compounds listed in Table 3-10. A definitive conclusion can not be reached, however, because the results presented are from different tests.

3.2.6 Pathogens Bacteria

There are primarily two routes by which pathogens may be released into the environment from incineration of infectious materials. These are: 1) discharge air streams; and 2) post-incineration residue.

As part of a recent test, 15 samples were taken from the stack of a hospital waste incinerator which had been charged with hospital waste containing pathogenic material[33]. Bacteria with a mean concentration of 231 colonies/m^3 of gas sampled were found in the stack as opposed to an ambient mean level of 148 colonies/m^3. However, due to experimental uncertainty, no statistically significant difference could be found between the two measurements.

Tables 3-12 and 3-13 show the results of a U. S. Department of Health Study which measured the bacterial population of residues from various types of municipal solid waste incinerators.[34] No data were located regarding bacterial populations in residue from hospital waste incinerators.

Evaluations of atmospheric release of pathogens in incinerator discharge air streams have primarily focused on the minimum operating temperature required to prevent this release. Laboratory studies report

TABLE 3-10. EMISSION FACTORS FOR SELECTED ORGANIC LOW MOLECULAR WEIGHT ORGANICS FROM HOSPITAL WASTE INCINERATORS

	Emissions Factor (lb/ton feed)	Reference Source
Ethane	<0.003	24
Ethylene	<0.02	24
Propane	<0.024	24
Propylene	<0.022	24
Trichlorotrifluoroethane	8.25×10^{-5}	21, 22
Tetrachloromethane	9.91×10^{-5}	21, 22
Trichloroethylene	2.39×10^{-5}	21, 22
Tetrachloroethylene	2.49×10^{-4}	21, 22

TABLE 3-11. EMISSIONS/FACTORS FOR CARBON MONOXIDE AND HYDROCARBON EMISSIONS FROM HOSPITAL WASTE INCINERATORS

Pollutant	Cedar Sinai[a] Medical Center Los Angeles, CA (ppmv)	Cedar Sinai[a] Medical Center Los Angeles, CA (lb/ton feed)	St. Agnes[b] Medical Center Fresno, CA (ppmv)	St. Agnes[b] Medical Center Fresno, CA (lb/ton feed)	Swedish-American[cd] Hospital Rockford, IL (ppmv)	Swedish-American[cd] Hospital Rockford, IL (lb/ton feed)	Emissions Factor (lb/ton feed)
Carbon Monoxide							
High	<50[e]	<1.32	<50	<1.69	19.0	1.17	<1.69
Low	<50	<1.32	<50	<1.69	0.0	0.0	<1.32
Average	<50	<1.32	<50	<1.69	9.5	0.59	<1.2
HC (as Propane)							
High	7	0.29	4	0.21			0.29
Low	3	0.12	1	0.05			0.05
Average	4	0.17	2	0.11			0.14

[a] Reference 26.
[b] Reference 27.
[c] Reference 41.
[d] Corrected to 50 percent excess air.
[e] Below detection limits.

TABLE 3-12. CHARACTERISTICS OF INCINERATORS EVALUATED FOR DESTRUCTION OF MICROFLORA[a]

Characteristics	Incinerator I	II	III	IV
Design Capacity[b]	500	500	1,200	200
No. of furnaces	2	4	4	2
Feed mechanism	Continuous	Batch	Continuous	Batch
Grate	Traveling	Circular	Rotary-kiln	Reciprocating
Operating temperature	1,800-2,000°F (980-1,090°C)	1,800-2,000°F (980-1,090°C)	1,200-1,700°F (primary) (650-925°C) 1,700-2,200°F (secondary) (925-1,205°C)	1,800-2,000°F (980-1,090°C)
Duration of burning (hr)	1.75-2.0	1.5-1.75	0.5-1.5	1.0
Total burning rate (tons/hr)	22	20	50	6.5
Quench water recirculated	No	No quench water	Yes	No quench water
Estimated volume reduction	80-85%	80-85%	80-85%	80-85%

[a] Source: Reference 34.

[b] Expressed as tons per 24-hour period.

TABLE 3-13. EFFICACY OF INCINERATOR OPERATIONS IN THE DESTRUCTION OF THE MICROFLORA ASSOCIATED WITH MUNICIPAL SOLID WASTE[a]

Material	Bacterial Population[b]	Incinerator[d]			
		I	II	III	IV
Solid waste	Total cells	7.6×10^{7}	4.1×10^{8}	5.6×10^{7}	3.8×10^{8}
	Heat resistant[c]	4.2×10^{4}	6.8×10^{4}	2.7×10^{4}	1.7×10^{4}
	Total coliforms	6.2×10^{5}	4.8×10^{6}	5.4×10^{5}	1.2×10^{5}
	Fecal coliforms	9.1×10^{4}	4.0×10^{5}	1.2×10^{3}	2.3×10^{4}
Residue	Total cells	4.4×10^{7}	1.7×10^{6}	1.2×10^{6}	7.1×10^{3}
	Heat resistant[b]	1.0×10^{5}	2.0×10^{4}	3.9×10^{3}	4.4×10^{3}
	Total coliforms	1.5×10^{4}	2.3×10^{2}	4.1×10^{1}	5
	Fecal coliforms	2.4×10^{3}	9	5	<1

[a] Source: Reference 34.
[b] Expressed as counts per gram.
[c] Expressed as spores per gram.
[d] See Table 3-12 for incinerator characteristics.

chamber temperature requirements of 575°F (302°C) for destruction of vegetative cells and 1,600°F (871°C) for spores.[35,36] The minimum operating temperature is an incinerator-specific phenomenon which can be determined only by challenging the unit with highly resistant organisms and measuring bacterial content of stack emissions to determine the temperature required for sterilization.[37]

3.2.7 Preliminary Emission Test Data

Presented in this section are preliminary emissions data for six hospital incinerators. Tables 3-14 through 3-16 present preliminary emissions data for three hospital incinerators located in California; these data, presented at the Hospital Waste Combustion Workshop in Baltimore, Maryland in May 1988, represent the high emission values obtained during stack tests.[38] Table 3-17 presents preliminary results of emissions tests performed at three biomedical waste incinerators (BWI) located in Canada.[39] All these emissions test data are preliminary; the accuracy of the data has not been assessed. For the sake of completeness and for future reference, these data are presented separately from the previous emissions data. Furthermore, due to the preliminary nature of the data, these data have not been included in the estimates of the emission factors.

In reference to Table 3-17, it should be noted that the concentrations of HCl reported for incinerators B1 and B2 are arithmetic averages and do not account for the variable flow rates as a result of batch testing. No microorganisms were detected in the air emissions or ash deposits of the three Canadian biomedical waste incinerators.

Continuous monitors were used to measure opacity, THC, and CO emissions at two of the Canadian biomedical waste incinerators. Measurements were taken over 24-hour periods when the incinerators were operating as well as when they were not operating (i.e., during "dormant" periods). The preliminary results showed that opacity levels were significant even during dormant periods and peaked during the ash clean-out period prior to incinerator startup. In addition, THC and CO emissions were also significant during dormant periods. These emissions are ascribed to the continued pyrolysis of unburned waste present in the ash and left in the furnace overnight, sustained by air entering through open doors or leaks.[50]

TABLE 3-14. PRELIMINARY HCl AND PM EMISSIONS TEST DATA

Hospitals	Emissions Controls	Incinerator Feed Rate (lb/hr)	HCl (ppm)	PM (gr/dscf)
A[a]	Wet Scrubber	550-805	1.86	0.003
B[b]	None	369-593	315	0.057
C[c]	None	70-100	770	0.04

[a] Two-chamber controlled air incinerator.

[b] Two-chamber controlled air incinerator.

[c] Single chamber incinerator with afterburner.

ND - Not Detected

TABLE 3-15. PRELIMINARY METALS EMISSIONS TEST DATA[a]

Hospital	Arsenic	Cadmium	Chromium	Iron	Manganese	Nickel	Lead
A[a]	0.01	0.50	0.07	5.90	0.06	ND	11.58
B	0.01	1.55	0.25	24.0	0.60	ND	27.9
C	0.29	7.43	ND	16.86	0.86	ND	102.57

[a] Units for all data are gm/ton.

ND- Not Detected

TABLE 3-16. PRELIMINARY DIOXIN AND FURAN EMISSIONS TEST DATA[a]

	Dioxin				Furan			
Hospital	TCDD	PeCDD	HxCDD	HpCDD	TCDF	PeCDF	HxCDF	HpCDF
A[a]	0.02	0.10	0.49	1.72	0.21	1.37	3.86	5.11
B	0.14	14.60	44.10	169.00	6.05	67.6	213.9	292.4
C	0.004	0.038	0.196	1.575	0.038	1.492	1.829	5.242

[a] Units for all data are ng/sec.

TABLE 3-17. PRELIMINARY RESULTS OF THREE BIOMEDICAL WASTE INCINERATORS LOCATED IN CANADA[a]

Hospital Incinerator	Total Particulate (g/kg)	Dioxins/Furans PCDDs (ng/dscm)	Dioxins/Furans PCDFs (ng/dscm)	Chlorobenzenes (ng/dscm)	Polychlorinated Biphenyls (PCBs) (ng/dscm)	Polyaromatic Hydrocarbons (ng/dscm)	HCl (ppm)	Total Hydrocarbons (ppm)	SO_2 (ppm)	NO (ppm)
B1	1	10	30	4 to 8	ND	ND	478	3	25	68
B2	1	32	260	NA	NA	NA	612	18	23	63
RF	13	NA	NA	NA	NA	NA	1,250	14	30	100

[a] Reference 39.

NA - Not Analyzed

ND - Not Detected

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4.0 CONTROL TECHNOLOGIES AND EFFICIENCIES

To date, hospital waste incinerators have operated largely without requirements for add-on pollution control equipment or special combustion modification techniques. Municipal waste incinerators, on the other hand, have received closer scrutiny in recent years and considerable attention has been given to potential emission control techniques. The process equipment and systems used to incinerate these two types of wastes are similar in design and operation, at least for the larger, controlled air incinerators. This section extrapolates knowledge which has been gained from municipal waste incinerators to hospital waste incinerators and considers the applicability of various emission control techniques.

There are three broad categories of methods which can be applied to the control of emissions from waste incinerators:

(1) Source Separation,
(2) Combustion Control, and
(3) Flue Gas Controls (add-on control devices).

The application of each of these categories of emission control to hospital waste incinerators is addressed in this section.

4.1 SOURCE SEPARATION

Source separation refers to both the segregation of infectious and non-infectious wastes and the removal of specific compounds from the waste stream prior to incineration. As discussed in Section 1.2, from the experience of hospitals in Illinois, it may be estimated that about 85 percent of a hospital's waste stream can be categorized as general refuse, while the remaining 15 percent is contaminated with infectious agents. Thus, segregation of wastes at the point of generation can reduce the volume of infectious waste significantly. During a visit of project personnel to the Iredale Hospital in Statesville, North Carolina, such waste segregation practice was observed through the use of colored trash bags. The extent to which this practice reduced infectious waste volume was not known, however.

After segregation of infectious and non-infectious wastes, further segregation of the non-infectious portion could be possible. Plastics and metal-containing components of the waste, such as sharps, could be segregated; this could result in lower HCl, polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzo-p-furans (PCDFs), and trace metal emission rates. However, no data are available on the effectiveness of such practices at hospital waste incinerators in lowering these emissions. Another approach to possibly lowering HCl and PCDD/PCDF emission rates would be to have hospitals use low chlorine content plastics. This could be accomplished if the health care industry were to use plastics such as polyethylene and polystyrene in place of polyvinyl chloride, which contains over 45 weight percent chlorine. Again, no data are available to indicate the effectiveness of such practices on emissions from hospital waste incinerators.

4.2 COMBUSTION CONTROL

Data presented in Section 3 illustrate that there is significant variation in the uncontrolled emission rates from hospital incinerators. These variations are partially due to variability in chemical and physical properties of hospital wastes, partially due to variations in incinerator design, and partially due to variation in operating practices. This section addresses how waste combustion processes influence emission rates for the pollutants of interest and how combustion process control may be used as an emission control strategy. The general format is to address each pollutant group separately, discussing how combustion processes influence the emission rate and how the adjustable process parameters may be used to reduce emissions and achieve emission control.

The following sections provide discussions of the relationships between combustion processes and emissions of major pollutants of concern, namely:

- acid gases,
- particulate matter,
- trace metals, and
- polycyclic organic matter (including dioxin and furans).

4.2.1 Acid Gas Control

The primary acid gas that will be emitted from a hospital waste incinerator is hydrochloric acid. As stated in Section 3.1, based on thermodynamic equilibrium considerations, any chlorine content in the waste will be effectively converted to HCl, assuming that there is sufficient hydrogen available. Therefore, based on the thermodynamic and kinetic consideration presented in Section 3.1, combustion modification does not appear to be a viable control approach for hydrochloric emissions from hospital incineration units.

From a combustion control standpoint, emissions of SO_2 are similar to HCl. Thus, combustion modification is not a viable approach for SO_2 emissions either.

Based on NO_x reduction techniques applied to other combustion processes, at least three control options may be applicable to reduce NO_x emissions from incinerator processes: flue gas recirculation (FRG), reburning, and ammonia (NH_3) injection. However, none of these techniques are currently being applied to hospital incinerators even though they are being used on MSW incinerators.

Flue gas recirculation is a technology which has been used for the control of NO_x in boilers. FGR introduces a thermal diluent and reduces combustion temperatures. However, lowering of flame and furnace temperatures could be counter to the control of PCDD/PCDF. The significance of the detrimental impact of reduced bulk temperatures on PCDD/PCDF emissions has yet to be determined. Testing completed on the Pittsfield MSW incinerator by the State of New York could provide information addressing the impacts of FGR when they become available. Information gained from this test and other future tests could be used to further evaluate the potential application of FGR to hospital incinerator units.

Reburning is used for a control technique which uses a hydrocarbon-type fuel such as natural gas or oil as a reducing agent. Hydrocarbon radicals produced by the reburning fuel react with NO_x to form N_2, H_2O, and CO_2. This control technology is being developed for use in fossil fuel-fired boilers because only minor modifications are required to the main heat release zone. The effectiveness of reburning for NO_x control in boilers has been shown to be a function of:

- Initial NO_x level: the reduction decreases as the initial NO_x level decreases.
- Reburning fuel type: nitrogen-free reburning fuels are most effective, particularly at low initial NO_x levels.
- Temperature: reburning effectiveness increases as the temperature of the reburning zone increases.
- Residence time: gas residence time in the reburning zone of at least 0.5 seconds is required to maximize the effectiveness of reburning.

Two aspects of the reburning process make it attractive for hospital incinerators. First, it is a relatively effective control technique, potentially reducing NO_x on the order of 50 percent. Second, the process of burning the secondary fuel increases both the flue gas temperature and the concentration of O, H, and OH radicals. The high radical concentrations in the fuel-rich reburning zone drive the gas speciation towards the equilibrium state of complete combustion (i.e., CO_2 and H_2O as products). Thus, reburning not only provides an approach for destroying NO_x, it also creates an environment which favors the destruction of any dioxins or furans created in the primary flame zone. Extensive research and development efforts would be required to develop reburning for hospital incineration, but the potential exists for a multi-purpose combustion control technology.

A third option available for NO_x reduction on incinerators is NH_3 injection. When injected into combustion gases, NH_3 can react with NO_x to form diatomic nitrogen (N_2) and water. The optimum temperature range for promotion of this NO_x reduction reaction is near 870 to 1000°C. Thus, for application to a controlled-air hospital waste incinerators, NH_3 would likely be injected either into the secondary chamber or into a seciton of the stack immediately following the secondary chamber. When this system (under the process name Thermal De-NO_x) was applied to an MSW incinerator, with NH_3 injectors located above the main combustion zone in the 870-930°C area, NO_x emissions were reduced by over 40 percent.[1] To date, no known NH_3 injection systems have been applied to hospital waste incinerators.

4.2.2 Particulate Matter Control

As stated previously, particulate matter exiting the furnace consists of both inorganic material entrained into the combustion gases and organic materials which were not completely burned. In evaluating the influence of combustion control on PM emissions, it is necessary to separate the organic and inorganic fractions and to distinguish between the volatile and non-volatile inorganic contributions.

When waste is fed into an incinerator, it is heated by radiant energy from the hot furnace walls and from burning combustion products above the bed. The waste is dried and, as the temperature increases, a devolatilization (pyrolysis) process begins. The released volatile matter is entrained by the underfire air and begins to burn. Heat transfer from the burning volatiles to the bed material helps to ignite the waste in the bed and sustain the combustion process. The non-volatile, inorganic constituents of the waste generally remain in the ash pit. Non-volatile inorganics can contribute to the PM emission rate if an ash-containing particle is entrained by the underfire air and bed combustion products as they pass through the waste bed into the primary chamber.

An ash-containing particle in the bed will be subjected to a series of forces including a drag force tending to accelerate the particle to the local air velocity and a gravity force tending to hold the particle in the bed. The drag force is proportional to the frontal area of the particle times the velocity differential squared. The opposing gravity force is simply gravitational acceleration times particle density times particle volume. Assuming a spherical particle, the gravity force varies with the diameter cubed. The ratio of drag force to gravity force will vary inversely with particle diameter. Thus, small particles are more likely to be entrained by the primary chamber combustion gases.

If it is assumed that the ash content of hospital waste is approximately 25 percent and that emitted PM is totally inorganic, then the uncontrolled PM emission rate data presented earlier in Table 3-5 may be used to estimate the extent of entrainment. The PM emission rates were shown to vary from 36.5 to 1.37 lb/ton refuse. This estimate would indicate that between 92.7 and 99.7 percent of the ash remains in the ash pit.

The volatile inorganic material in the feed will also contribute to the total PM emission rate. It is convenient to discuss combustion control of this PM fraction in the context of trace metal emission even though all of the trace metals emitted may not be associated with the particulate. A discussion of trace metal emissions is presented in Section 4.2.3.

Finally, organic compounds are also associated with emitted PM. These organic components are generally heavy hydrocarbons, products of incomplete combustion (PICs), or polycyclic organic matter (POM). An extensive discussion of these emissions and potential combustion control is presented in Section 4.2.4.

4.2.3 Trace Metals Control

In Section 3.0, the available trace metal emissions data from hospital incinerators were discussed and it was pointed out that many of the volatile metals of concern tend to selectively deposit on the smaller particles. The physical processes responsible for these phenomena are complex, as is the potential influence of combustion processes on the associated phenomena. The following provides a brief review of key features which may be significant relative to hospital incineration combustion control.

The majority of the available research concerning the process of fine particle metal enrichment has been performed on pulverized coal-fired utility boilers. Those conditions are somewhat different from the conditions found in hospital incinerators, but the basic processes should be similar in both systems. It has been found that the distribution of volatile metals among the different size fractions of ash is influenced by the quantity of ultra-fine particulate matter produced during combustion. Figure 4-1 illustrates this point in a plot of the fraction of arsenic and antimony collected with the ultra-fine particles (referred to as fume) versus the fraction of the total ash vaporized. A surface deposition model to interpret these data was developed. The model's predictions for quantities of trace metal deposited on ultra-fine particles are presented as solid lines on Figure 4-1.

The issue of how the metals are distributed throughout the total fly ash as a function of particle size has health effect implications as well as being an issue of engineering significance. Based on the probable

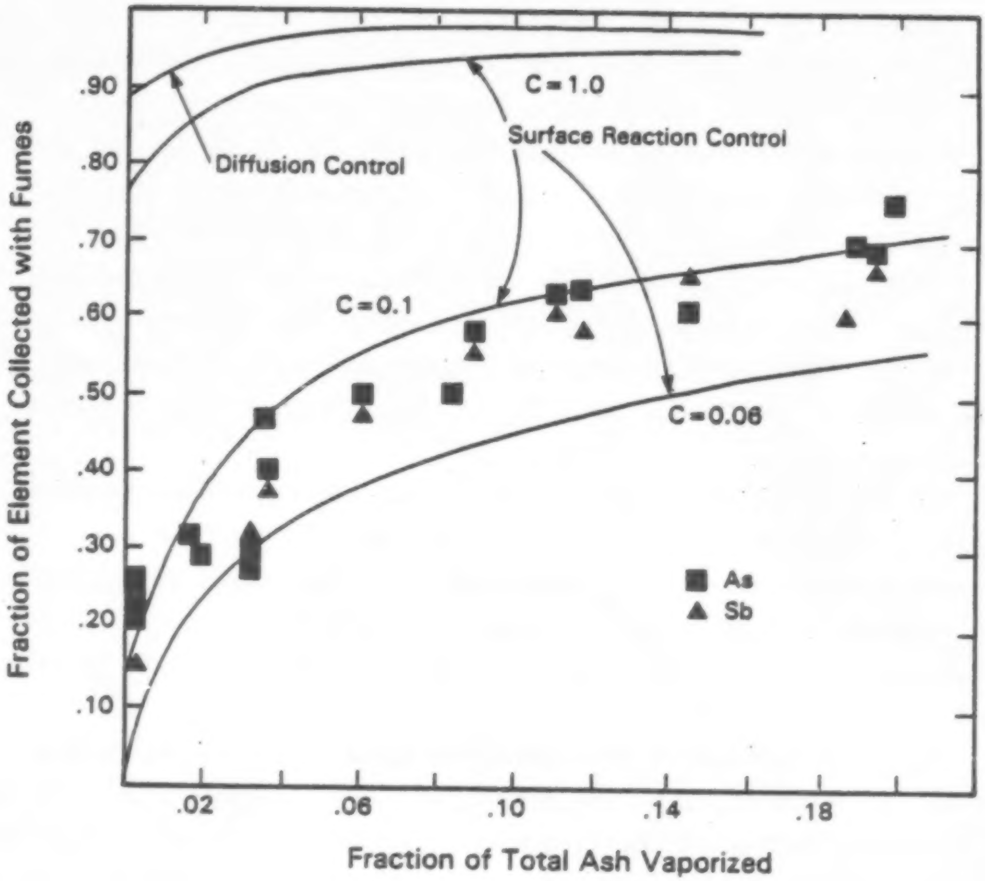

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Figure 4-1. Fraction of As and Sb collected with Fume as a Function of the Extent of Total Ash Vaporization (Data Points)

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mechanisms of fine particulate formation, it is suspected that the trace metals should tend to concentrate on the surface of fine particles rather than being uniformly distributed throughout the entire particle size range. The theory is that refractory oxides which are vaporized in the flame would be the first species to condense and would become the nuclei for the fine particulate matter. As the combustion gases cool, volatile salts of alkali metals and other volatile trace species would be expected to condense on the outer surface of these particles.

A group at MIT, led by Professor Adel Sarofim, has confirmed this theory in several experimental studies.[2] Figure 4-2 illustrates their findings in a plot of the concentration of selected species versus reciprocal particle diameter. The elements Fe and Mg, which form the core of the particles, show no size dependence while those present as a surface coating show concentration variation proportional to 1/d. Note that the trace metals of concern for hospital incinerators were largely present as surface coatings.

The key to the above observation is that the ultra-fine particles present a very high specific surface area and, thus, receive a disproportionate share of the condensing elements. Based on the findings of this research, any process that enhances refractory oxide vaporization would be expected to increase the number of sub-micron particles and to enhance the fine particle enrichment process.

The above information provides clues relative to the mechanisms responsible for trace metal enhancement on sub-micron particles. It does not, however, define a combustion control approach to minimize trace metal emissions. Incinerators operated with relatively higher temperatures in the fuel combustion zones should have higher concentrations of sub-micron particles which could potentially increase the trace metal enrichment process. Therefore, the use of controlled air, or two-stage, incineration with its lower primary combustion zone temperatures should reduce or minimize trace metal emissions. Unfortunately, data from retort-type incinerators are not available as yet to confirm this hypothesis.

4.2.4 Polycyclic Organic Matter (POM), PCDDs, and PCDFs

Available data from MSW incinerators indicate that the PCDD and PCDF emission rates are closely related to efficiency of the combustion process.

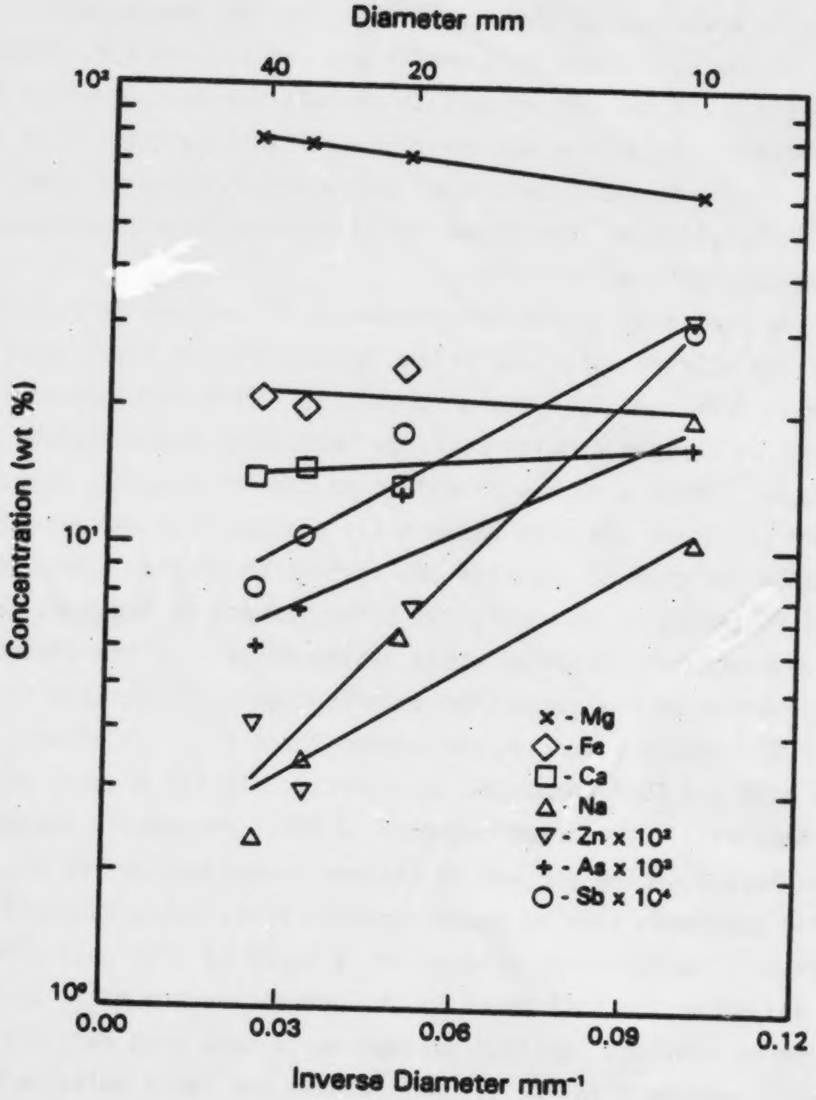

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Figure 4-2. Concentration of Selected Elements in Ultrafine Particulates as a Function of Reciprocal Particle Diameter

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Generally speaking, when the flame temperature and combustion efficiency are increased, PCDD and PCDF emission rates decrease. Due to the overriding toxiological importance of these pollutant species, discussion will be presented on how poor combustion conditions can lead to POM, dioxin and furan emissions and how the combustion process may be controlled to minimize these emissions. Emissions and their control will be considered from the standpoint of the thermodynamic equilibrium and kinetics of combustion reactions. In addition, the formation of dioxins/furans subsequent to the combustion zone will be considered.

The vast majority of the information on dioxin and furan emissions has been obtained only recently and primarily consists of stack emission rate measurements from municipal waste combustors. This information is taken primarily from testing results at large industrial and municipal incinerators; little work has been done on smaller hospital waste incinerators. There are also essentially no data from experimental programs specifically designed to identify the combustion processes responsible for PCDD/PCDF formation or to verify the effectiveness of proposed combustion control approaches on hospital waste incinerators. In the absence of direct data, discussion of how combustion modification might be used to control PCDD or PCDF emissions must be considered theoretical in nature.

The PCDD and PCDF compounds are dicyclic, nearly planar, aromatic hydrocarbons within the broad category of POM. Polycyclic organic matter emissions have been the subject of intense investigation for many years with multi-ring compounds such as benzo(a)pyrene (BaP) being the primary species of interest. The following discussion is based on available information on how POM emissions are influenced by the combustion process. In basing the discussion on POM, the implicit assumption is made that variation in POM emissions corresponds to variation in dioxin and furan emissions.

Equilibrium Considerations. If waste material is mixed with air and allowed to react for sufficient time, the concentration of the resultant products is determined by the elemental composition of the mixture (moles of

C, H, N, O, Cl, etc.), the reaction temperature, and the thermodynamic properties of the species. Consider first the case of oxidizing conditions (excess air) in which the overall oxidation process is represented by:

$$\text{Waste} + n_1O_2 \longrightarrow n_2CO_2 + n_3H_2O$$

where n_1, n_2 and n_3 are the stoichiometric coefficients required to balance the reaction and are dependent on the chemical structure of the waste. The equilibrium level of the unreacted waste in the combustion products is related to the concentrations of CO_2, O_2 and H_2O by the equilibrium constant:

$$K_p = \frac{P_{CO_2}^{n_2} \, P_{H_2O}^{n_3}}{P_{waste} \, P_{O2}^{n_1}}$$

where P represents the partial pressure of a given constituent and K_p is the equilibrium constant. The equilibrium constant is related fundamentally to a measurable thermodynamic property called the Gibbs free energy ($\triangle G$) by:

$$K_p = EXP\ (-\triangle G/RT)$$

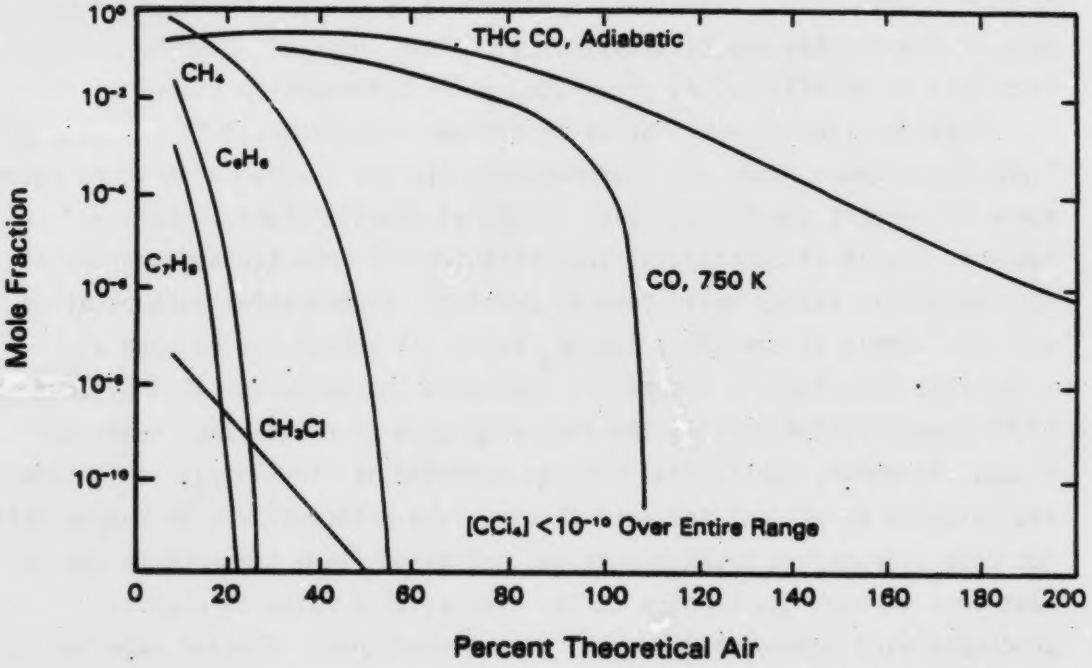
where T is temperature and R is the universal gas constant. Gibbs free energy values are compiled in many sources. For typical stack gas CO_2, H_2O and O_2 concentrations of 8 percent, the Gibbs free energy required for there to be 1 ppb equilibrium level of waste at 1,000K is roughly 40 Kcal/mole. The Gibbs free energy of furan at 800K is reported to be 492 Kcal/mole.[3] Thus, Gibbs free energy considerations predict an equilibrium furan partial pressure of less than 10^{-100}. The Gibbs free energy values for dioxins are even larger than those for furans; thus, the equilibrium concentration under oxidizing conditions would be expected to be even less. These considerations show that given sufficient reaction time and mixing, the fundamental equilibrium limit for dioxins and furans may be considered zero for overall fuel-lean conditions, even at typical incineration operating temperatures.

Since PCDDs and PCDFs can be formed in hospital incinerators, it is important to identify conditions where their presence is thermodynamically favored. An obvious area to examine is the high temperature, oxygen starved environment which is characteristic of isolated regions within poorly mixed combustion processes. An initial area to examine is high temperature pyrolysis without air which is the limiting case for poor mixing.

TRW, Inc. performed an extensive series of equilibrium calculations for incineration of military pesticides.[4] An initial set of calculations indicated that solid carbon (graphite) was a predominant species. Recognizing the kinetic limitations of graphite formation, a second set of calculations were performed eliminating graphite as a possible product species. Those results indicated greater than 1 ppm concentrations of a wide variety of POM species as well as chlorobenzenes and chlorophenols (potential precursors to dioxins and furans).

The issue of poor mixing can also be addressed by examining the equilibrium product distributions for combustion of various chlorinated benzene/air mixtures.[5] Sample results are shown in Figure 4-3 as concentration versus percent theoretical air assuming that the mixture is at the adiabatic flame temperature. With at least 45 percent theoretical air, formation of light hydrocarbon gases (e.g., CH_4 and C_2H_2) is avoided. At 20 percent theoretical air, the formation of benzene or toluene as equilibrium products is avoided. This leads to the postulation that POM, dioxins and furans are thermodynamically favored only if the incinerator creates very fuel-rich (and hence oxygen-poor) pockets of gas at low temperatures in the presence of chlorine.

The above discussion illustrates two significant aspects of combustion control for POM. First, existence of these species (either in the flame or the exhaust) indicates a combustion process characterized by insufficient mixing and by local fuel-rich pockets of gas. These are the conditions which characterize the primary combustion chambers of controlled air incinerators. However, at temperature levels typically encountered in these



Source: Reference 5.

Figure 4-3. Adiabatic Equilibrium Species Distribution

units, there is no thermodynamic barrier to achieving essentially zero emission levels for these species and their precursors that are below the ppt levels.

Kinetic Considerations. The preceding discussion addressed equilibrium formation of POM under excess air and starved air conditions. It is important to recognize that combustion of any fuel proceeds through a complex series of reaction steps leading toward (but not necessarily reaching) the product distribution predicted by equilibrium calculations. Some of these steps may be kinetically limited, however, causing certain reactions to be effectively terminated at an intermediate state.

Consideration of equilibrium conditions (see Figure 4-3) indicate that light hydrocarbon gases are thermodynamically not favored at mixture ratios above 45 percent theoretical air. Chemical kinetic limitations may, however, result in substantial concentrations of unburned hydrocarbon at stoichiometric ratios well above 45 percent. Experimental data obtained in the development of the EPA's low-NO_x heavy oil burner may be used to illustrate this fact.[6] Figure 4-4 indicates the measured total hydrocarbon (THC) concentration exiting the fuel-rich zone of a two-stage heavy oil flame. As shown, substantial THC was detected at first stage stoichiometric ratios below 80 percent theoretical air. The principal factor responsible for this hydrocarbon breakthrough was depressed flame temperature due to heat loss through the furnace walls. The kinetic rates of chemical processes vary exponentially with local temperature. Similar experiments, conducted in a higher temperature environment, showed negligible THC concentrations until the fuel-rich zone stoichiometry was less than about 60-65 percent theoretical air.

In the above tests, the transition from fuel-rich to fuel-lean conditions was achieved through the use of multiple air jets designed to achieve thorough mixing of air with the effluent from the fuel-rich zone. By changing the split between primary and secondary air, it was possible to vary the fuel-rich zone stoichiometry while maintaining a constant overall excess air condition. In many respects, this is similar to the basic design in a controlled air incinerator. An important observation is that whenever the primary zone stoichiometry was sufficiently fuel-rich to cause

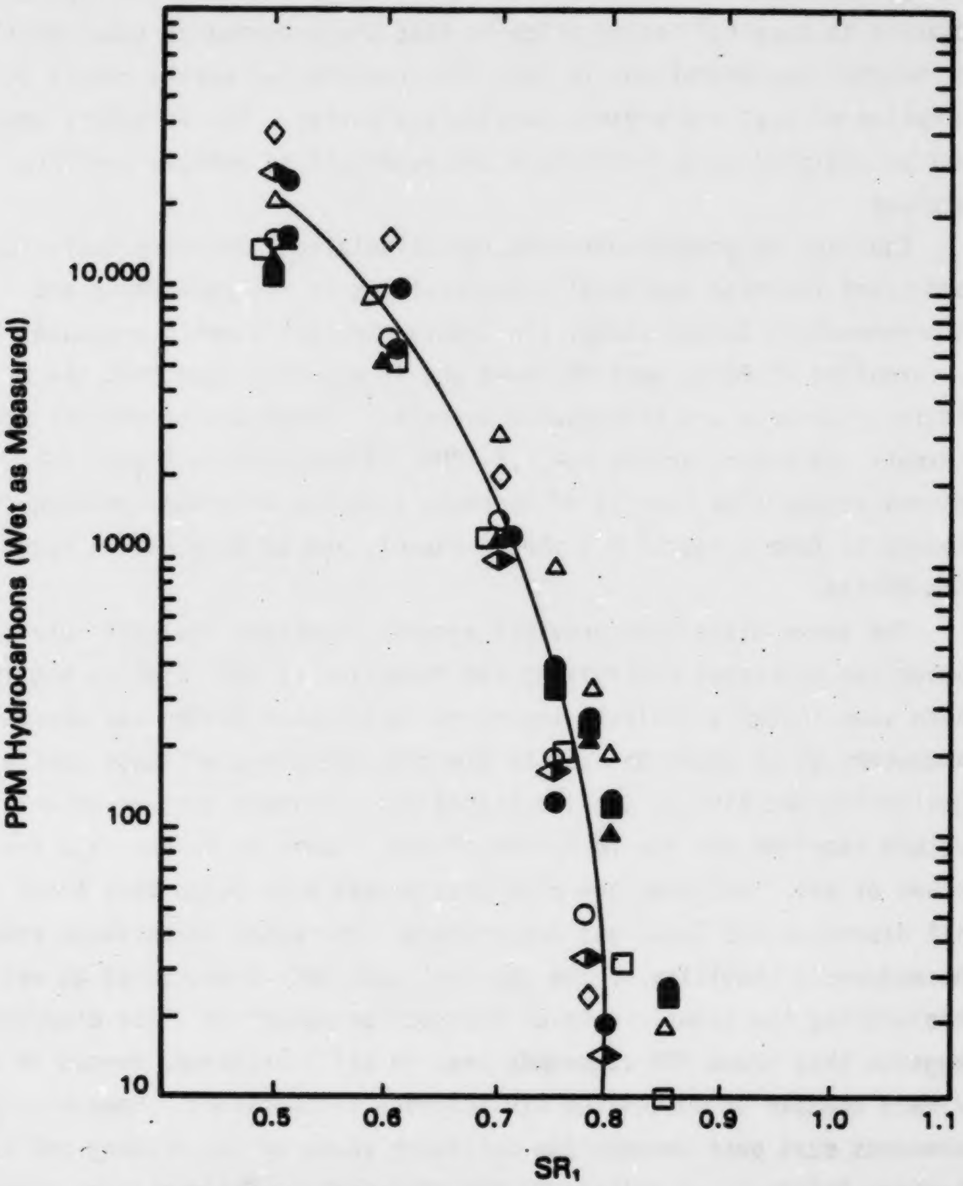


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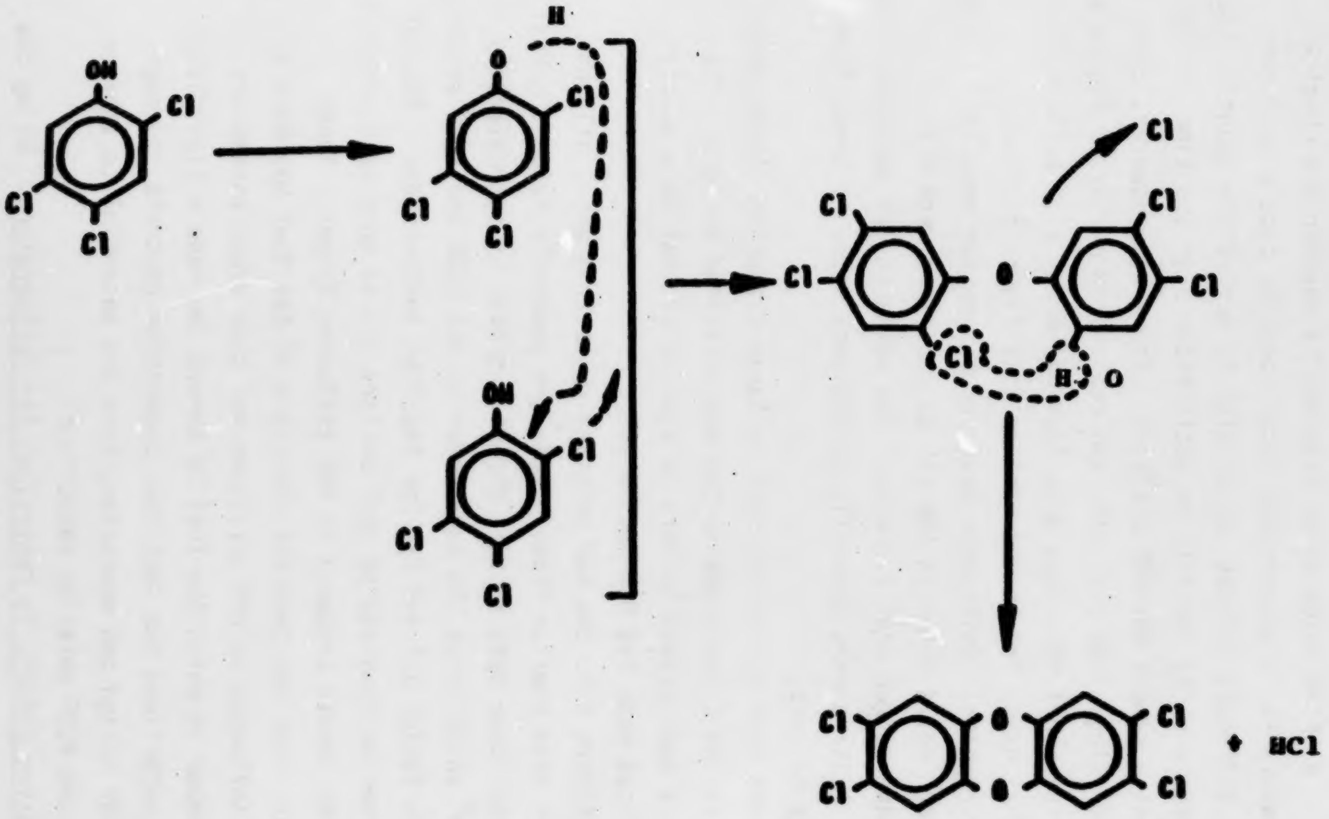
Figure 4-4. First Stage Hydrocarbon Production

hydrocarbon breakthrough in the primary zone exhaust, there was a precipitous increase in the boiler exhaust smoke level. The important point relative to hospital incineration is that the presence of substantial hydrocarbon concentrations in fuel-rich regions can easily result in the formation of soot and organic particulate matter. The secondary chamber must be designed to accommodate these materials to achieve complete burn-out.

Equilibrium product distribution calculations for very fuel-rich conditions indicate ppm level concentrations of chlorobenzenes and chlorophenols. In one study, the likely chemical kinetic processes leading to formation of PCDDs were reviewed and it was concluded that the prime dioxin precursors are chlorinated phenols.[7] Shaub and co-workers suggested a kinetic path for forming 2,4,7,8-TCDD, illustrated in Figure 4-5. The process proceeds by removal of hydrogen from the OH group, joining of two phenols to form a reactive 2-phenoxyphenol, and an elimination reaction to form dioxin.

The above discussion provides several important insights into the combustion processes controlling the formation of POM, dioxins and furans. Those same insights indicate important incinerator design and operating parameters which might be used to minimize emissions of those species. Equilibrium and kinetic considerations both indicate that an essential feature required for the formation of POM, dioxin or furans is a fuel-rich pocket of gas. Defining how rich that pocket must be to form these species will depend on the local gas temperature. Increased temperature reduces the thermodynamic stability of the species (and their precursors) as well as accelerating the kinetic rate of destruction reactions. The discussion suggests that these POM compounds are, in all likelihood, formed in the primary chamber of controlled air hospital incinerators. However, these compounds must pass through the oxidizing zones in the primary and secondary chambers before being emitted to the atmosphere. The residence time and temperature characteristics of the overall combustion process will dictate, in large measure, the extent to which these materials are destroyed before flue gases are emitted.


OH
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H
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O
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Cl
+ HCl

Source: Reference 7.

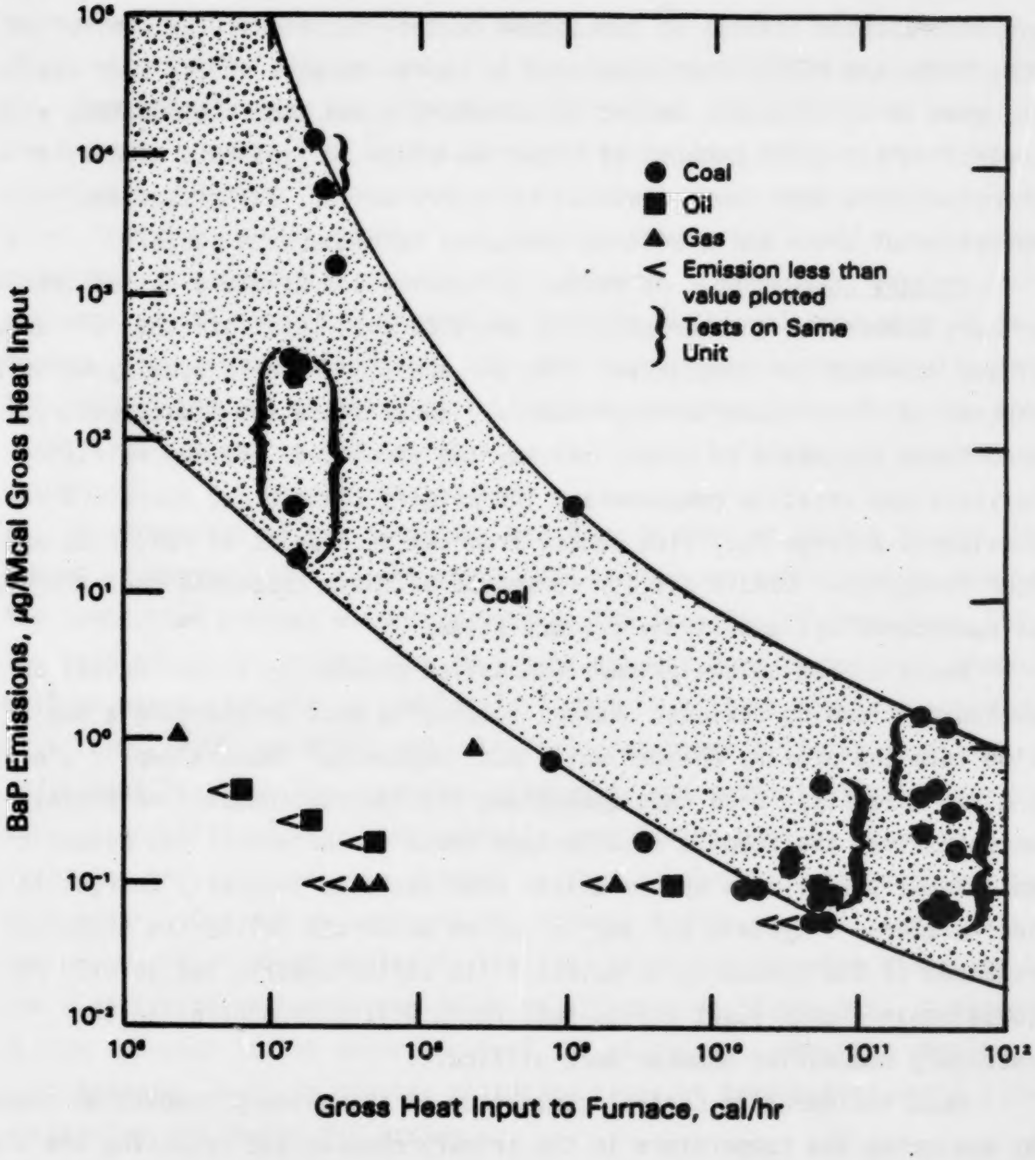
Figure 4-5. One Possible Formation Mechanism for 2,3,7,8 - TCDD

Fuel Effects. A third issue to be examined is whether the chemical form of hospital waste has a significant impact on POM, dioxin or furan emissions. It is difficult (if not impossible) to accurately quantify the chemical form of waste being fed into an incinerator over the time period required to extract a sample for POM analysis. There are, however, data quantifying POM emissions from gas, oil, and coal-fired boilers. Figure 4-6 shows benzo(a)pyrene (BaP) emissions data from different size boilers firing coal, oil or natural gas. The shaded area in this figure represents coal-fired boiler results. Units with heat inputs greater than 10^{10} cal/hr were utility boilers while units in the 10^7 cal/hr range were small stoker-fired or hand-stoked coal furnaces. The measured BaP emissions from gas and oil-fired boilers were generally on the same order as those from coal-fired utility boilers.

Utility boilers burn pulverized coal in large diffusion flames which are very similar to the flame types in gas and oil-fired boilers. The flame produced by a hand-stoked boilers is similar to that in a poorly designed and operated mass fed MSW incinerator.

As noted in Figure 4-6, the BaP emission rates from gas-, oil and coal-fired boilers with similar flame shapes are generally below 1 g/Mcal.[8] For comparison with other data in this report 1 g/Mcal is approximately equal to 500 ng/m^3 which is on the same order as the PCDD and PCDF emission rates indicated in Tables 3-7 and 3-8 for hospital incinerators. The BaP emission rates from the hand-stoked coal boilers are as much as 5 orders of magnitude above the levels produced by the diffusion flames. These comparisons suggest that the chemical structure of the fuel may have a relatively minor influence on POM emissions but that other parameters related to the manner in which the fuel is burned can have a significant influence. This underlines the fact that combustion controls, through careful incinerator design and operation, have the potential to achieve significant PCDD and PCDF emission reductions.

Air Distribution Effects in Controlled Air Incinerators. Using the waste burning process description of Section 3.1.4.1 in conjunction with the equilibrium, chemical kinetic, and fuel composition considerations of this section, it is possible to identify a variety of combustion control approaches for POM, PCDD and PCDF emissions, all based on elimination of



Source: Reference 8.

Figure 4-6. Benzo(a)Pyrene Emissions from Coal, Oil, and Natural Gas Heat-Generation Process

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fuel-rich, low temperature pockets. A discussion of the design or operating conditions which lead to the formation of these pockets follows.

Controlled air incinerators will be used for the purpose of discussing air distribution effects on combustion control techniques for control of POM, PCDD, and PCDF. This type unit is chosen because of its wide use in the past 10 to 15 years. Retort incinerators share some similarities with controlled air units because of their two-stage design; this discussion will therefore also have some relevance to retort units. The design and operation of these units will be discussed by combustion stage.

Primary Combustion. As stated in Section 2.1.2, waste is fed into the primary combustion chamber which is operated with less than the full amount of air required for combustion. The air addition rate is usually 40 to 70 percent of stoichiometric requirements. Under these sub-stoichiometric conditions the waste is dried, heated, and pyrolized, thereby releasing moisture and volatile components. The primary chamber can therefore be considered a large fuel-rich pocket from the standpoint of POM, PCDD and PCDF formation. Conditions for formation of these compounds can, therefore, be considered optimum in the primary stage.

Waste is fed to the primary combustion chamber by either manual or mechanical loading devices. Manual loading is done by charging a bag at a time into the primary chamber while most mechanical loaders employ a hopper and ram assembly. Both feed mechanisms are non-continuous feed processes which deliver the feed in a batch-type manner. Therefore, the potential for an extremely fuel-rich system exists when waste is initially charged to the incinerator. A dynamic air supply system which can follow the transient is required if the system is to maintain its stoichiometric set point. Failure to maintain a consistent air-to-fuel ratio will make control in the secondary combustion chamber more difficult.

Most incinerators control combustion in the primary combustion chamber by measuring the temperature in the primary chamber and adjusting the air flow rate to that chamber to meet a temperature set-point. When temperatures are too low, air is added to accelerate the burning process. Conversely, the air rate is decreased when the temperature is too high.

In conclusion, the operation of the primary combustion chamber is such that a fuel-rich combustion environment exists. Smooth control of the air-to-fuel ratio is needed to counteract transients due to the feed mechanism; this will minimize the amount of fluctuation in the gas rate and characteristics of the gas entering the secondary combustion chamber.

Secondary Combustion. Moisture, volatiles, and combustion gases from the primary chamber flow upward through a connecting section where they are mixed with air prior to entering the secondary combustion chamber. If the gases from the primary chamber are hot enough they will self-ignite when mixed with the secondary chamber air. However, a burner is located near the entrance to the secondary chamber to provide additional heat when it is needed. The air injection rate into the second chamber is generally between 100 and 140 percent of total stoichiometric requirements. Thus, the total combustion process in the incinerator (including both stages) operates at between 40 to 110 percent excess air.

If operation of the secondary air flow is kept at design levels, the amount of oxygen added to the combustion process is sufficient to complete the combustion process without exceeding the lean fuel flammability limits. The critical issue is that the fuel-rich exhaust from the primary chamber must be mixed with air on a molecular level to achieve complete destruction of all POM, PCDD and PCDF, and potential precursors. Simply injecting additional air into the secondary chamber is not sufficient to ensure high combustion efficiencies. Consequently, great care must be taken in designing the secondary air chamber so that complete and thorough mixing will occur. One design approach to increase mixing currently in use is to introduce air at right angles to the flow of primary chamber gases and to use a series of staggered manifolds on either side of the gas. A second design approach is the enlargement of the secondary combustion chamber. This approach leads to greater residence times at temperature while also increasing the chance for mixing.

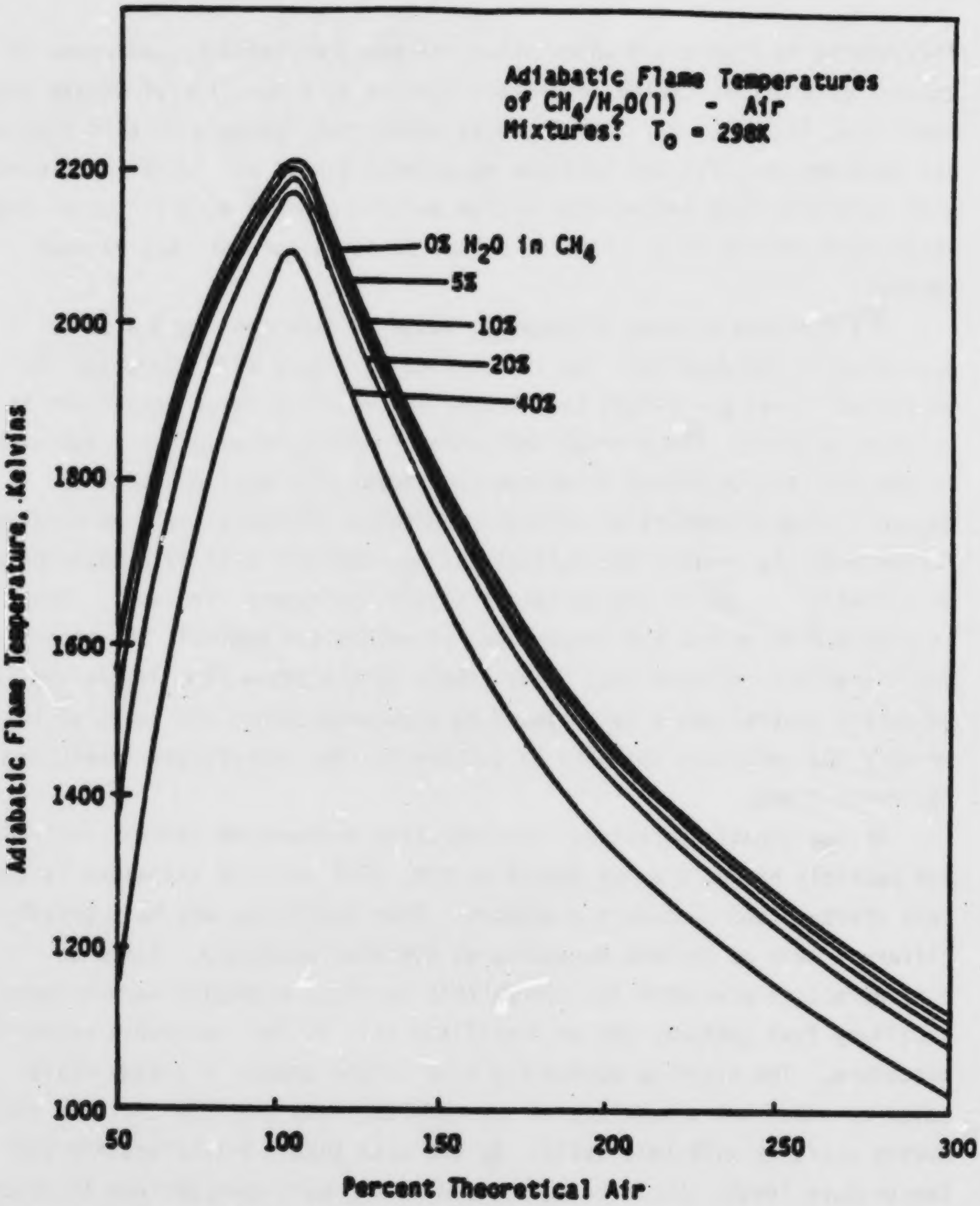
From an operational standpoint, the primary air flow rate control, secondary air flow rate control, and the extent of mixing in the secondary chamber, all could have a significant impact on POM, PCDD and PCDF emissions. Further research is required to better understand how incinerator design and operating parameters influence these emissions.

Thermal Environment. In EPA's Tier 4 study, it was observed that trends in PCDD and PCDF emissions could be detected based on the combustion temperature.[9] It was also noted in this report that MSW incinerators burning high moisture content waste tended to have low combustion temperatures and higher PCDD/PCDF emissions. The following discussion considers the theoretical relationship between temperature and emission rates for PCDDs, PCDFs, and other POMs.

Thermal environment and chemical kinetic processes are intimately related to each other. Flame temperature rise is the result of chemically converting fuel to combustion products while the rate of the chemical reactions is exponentially dependent upon the local temperature. In the discussion of equilibrium considerations it was shown that formation of fuel-rich pockets of gas favors production of POM, PCDD and PCDF. In the discussion of kinetic processes, Figure 4-4 showed that substantial hydrocarbons can persist in 80 percent theoretical air mixtures if there is heat extraction. Thus, removing heat from combusting gases tends to increase the stoichiometric ratio at which hydrocarbon species can persist.

An important set of variables influencing flame temperature is the excess oxygen level in the combustor and the moisture content of the waste. To illustrate these effects, a series of adiabatic flame temperature calculations were performed as a function of percent theoretical air. To demonstrate that flame temperature is controlled by combustion of waste volatile matter, methane was used as the fuel for these calculations. To simulate the moisture content of the waste, various quantities of liquid water (0-40 percent) was added to the "fuel." Results from these calculations are presented in Figure 4-7.[10] As shown, increasing the combustion air from 150 to 200 percent of the theoretical requirement decreases the adiabatic flame temperature by approximately 300°C (540°F). At 150 percent theoretical air (50 percent excess air), increasing the moisture content from 0 to 40 percent decreases the adiabatic flame temperature by approximately 150°C (270°F).

The important operational consideration is to maintain the excess air in a range which is high enough to insure that oxygen is available for fuel burnout but low enough to prevent excessive depression of the flame temperature. The requirement for operation within an excess air window is



Source: Reference 10

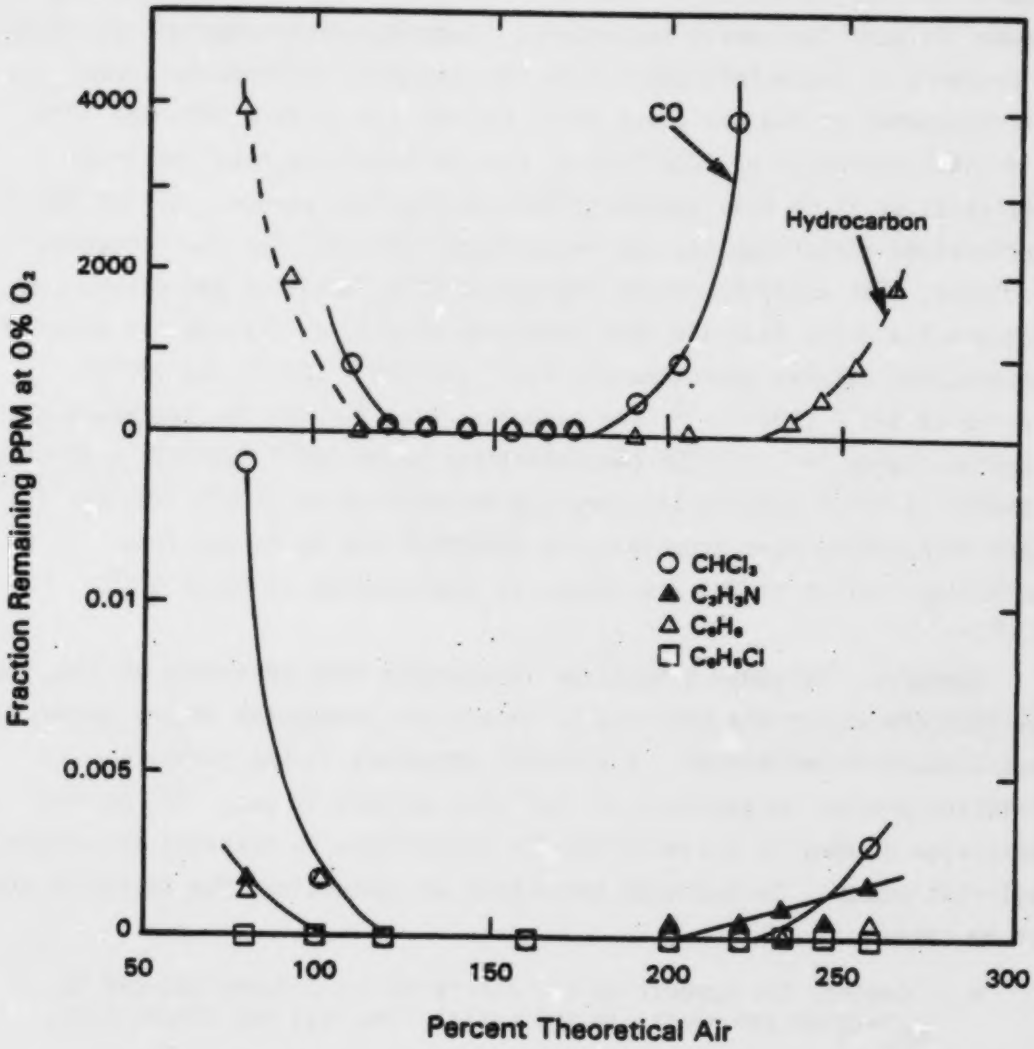
Figure 4-7. Variation of Adiabatic Flame Temperature with Percent Theoretical Air and Percent Moisture in the MSW

illustrated in Figure 4-8 which shows the measured total hydrocarbons in the exhaust of a highly cooled laboratory furnace as a function of excess air level (see Reference 5). It should be noted that the data in this figure are hardware-specific and that the acceptable excess air operating window will vary with both incinerator design details and characteristics of the waste being burned (e.g., heating value, moisture content, and halogen content).

The moisture content of hospital waste is dependent on the daily operation of the hospital. As illustrated in Figure 4-7, adjusting the excess air level can offset the thermal influence of large variations in moisture content. The thermal influence of adding 40 weight percent water to the fuel may be offset by decreasing excess air level by about 20 percent. From a combustion control standpoint, hardware could be developed to continuously monitor the exhaust gas H_2O content; that data could be used in a control system to appropriately adjust the excess air level. Research is required to define the proper mode of excess air control, but theoretical considerations indicate that it is likely that minimum POM, dioxin and furan emissions control would be achieved by adjusting excess air rates in the primary and secondary chambers to achieve desired temperature levels and gas residence times.

An additional operational consideration influencing thermal environment and possibly having a major impact on POM, PCDD and PCDF emissions is the unit start-up and shut-down procedure. Some facilities may have greatly different warm-up periods depending on operator awareness. Based on considerations presented earlier in this section, extensive warm-up using auxiliary fuel (natural gas or distillate oil) is the preferable operating procedure. The start-up period may have little impact on steady-state emission rates but a substantial mass of POM, PCDD and PCDF could be emitted during start-up with cold walls. By the same token, sufficient air and temperature levels should be maintained during burn-down periods to assure complete combustion.

Post-Combustion Formation Mechanisms. In addition to formation in fuel-rich pockets of the incinerator combustion zone, it is possible that PCDD and PCDF may be formed by flue gas reactions taking place downstream of the first or second stage combustors.



Source: Reference 11

Figure 4-8. Hydrocarbon Breakthrough as a Function of Percent Theoretical Air

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Several mechanisms have been hypothesized by various researchers to account for the formation of PCDD and PCDF downstream of the combustion chamber in municipal waste combustors. These hypotheses include a) reaction of products of incomplete combustion, for example, chlorophenols and chlorobenzenes in the gas phase or on the fly ash to form PCDD and PCDD; b) de novo synthesis of PCDD/PCDF on fly ash involving metal chloride catalysis; or c) de novo synthesis from particulate carbon. All of the hypothesized mechanisms include temperature "windows" for the formation reactions. For example, recent studies of PCDD formation and destruction by Vogg and Steiglitz indicate that formation of PCDD in fly ash can occur at temperatures between approximately 430°F and 750°F (220°C and 400°C), peaking at 570°F (300°C).[12] The authors heated fly ash for two hours and found no change in PCDD/PCDF concentrations below 390°F (200°C), a 10-fold increase at 570°F (300°C) and complete destruction at 1110°F (600°C).[13,14] Other researchers have proposed that PCDD/PCDF can be formed from particulate carbon in MWC flue gases at temperatures of about 570°F (300°C).[15]

Summary. The above discussion illustrates that emissions of POM, PCDD and PCDF are either the products of incomplete combustion or are formed by post-combustion mechanisms. A critical component in the combustion formation process is presence of fuel-rich pockets of gas. The primary combustion chamber in a controlled air incinerator is operated as a large fuel-rich pocket. To maximize the extent of combustion, the following steps can be taken:

- o Control the combustion air supply to the primary chamber to minimize transients in the outlet flow rate and composition;
- o Proportion combustion air between the primary and secondary chambers to maintain desired temperatures; and
- o Promote efficient mixing of air and combustion gases in the secondary chamber.

Each of these combustion parameters are adjustable during the incinerator design and/or as part of the unit operating procedure. The assertion that combustion-generated PCDD and PCDF emissions can be reduced by combustion control is clear, but the types of modifications likely to be effective will depend upon the specific design and operating conditions of a given model and size. That is, combustion modifications must be tailored to the specific type of incineration hardware under consideration. Appropriate control strategies for existing facilities must be evaluated on a case-by-case basis and some processes may require extensive hardware modification and/or altered operational procedures.

To the extent that PCDD/PCDF emissions are formed downstream of the combustion chambers, emission reductions will be influenced by the mechanisms involved and practices employed in this area. If emissions are the result of reactions between products of incomplete combustion (PICs), these products must be avoided in the temperature window in which the reactions occur. Possible emission reduction techniques would be the elimination of PICs in the secondary combustion chamber by operating the chamber at higher temperatures and/or larger gas residence times. Another approach would be to remove the PICs from the flue gas stream either by scrubbing an adsorption. If PCDD/PCDF emissions are the result of de novo synthesis on fly ash or from particulate carbon within a given temperature window, then the removal of fly ash and carbon at temperatures above the critical window would reduce flue gas emissions. However, it may still be necessary to rapidly quench the captured particles (e.g., with a scrubbing liquid or air) or to cover their active surface area with an inert material (e.g., powdered lime) in order to minimize subsequent de novo synthesis from captured particles. The processes available for such flue gas treatments are discussed in the next section.

4.3 FLUE GAS CONTROLS

Add-on devices may be employed for post-combustion treatment of flue gas. As shown in Section 3.0, two devices presently in use on hospital incinerators are fabric filters (baghouses) and wet scrubbers. Other potential add-on controls not presently in use are dry scrubbers and dry injection. Dry scrubbers and dry injection have demonstrated acid gas and organic emissions control on MSW incinerators and, when coupled with fabric filters, offer good particulate control as well. In addition, after-burners are potential controls for organic compound emissions. These same devices are candidates for control of emissions from hospital waste incinerators.

4.3.1 Fabric Filters (Baghouses)

Fabric filters offer very high efficiencies for particle removal from flue gas with attainable efficiencies greater than 99.9 percent. Currently, there are at least four MSW incinerator installations utilizing baghouses in the U. S.[16] Similar efficiencies would be expected for hospital waste incinerators because of the similar nature of the wastes. At least one baghouse has been installed and operated on a hospital waste combustor (see Section 3.2.2).

Fabric filters rely on porous glass fabric to facilitate removal of very fine PM. Figure 4-9 shows a typical arrangement. Collected PM is "shaken," either mechanically or by air, from the bag and disposed of with bottom ash from the incinerator. Some advantages and disadvantages of baghouses are as follows:[17]

Advantages

1. High PM removal efficiencies can be obtained.
2. High efficiencies for finer PM means good removal of those metals which concentrate on fine PM.
3. There are no wastewater disposal requirements.
4. Variations in flue gas flow rate or chemical composition do not usually affect fabric filter performance.
5. Submicron particle collection improves as the thickness of the dust layer on the collection surface increases.

Disadvantages

1. Fabric filters are designed only for PM control and do little to control gaseous pollutants.
2. High pressure drops may occur if bags become plugged with solids which could lead to large power requirements.
3. The upper temperature limit of most widely used filter media is about 260°C (500°F).
4. "Sparklers" (i.e., incandescent waste particles) carried by the flue gas can cause fires in the fabric filter.

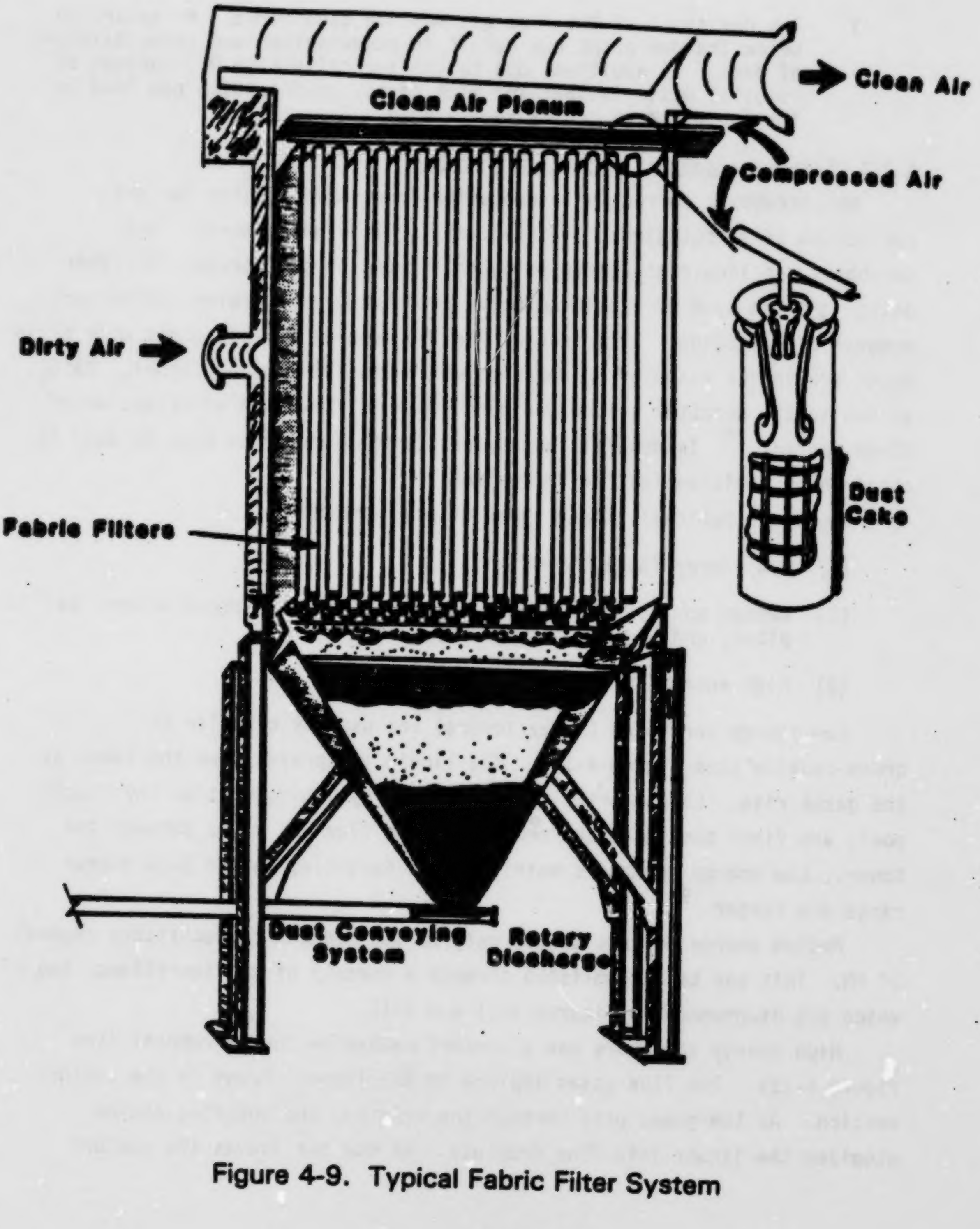

Clean Air
Clean Air Plenum
Compressed Air
Dirty Air
Dust Cake
Fabric Filters
Dust Conveying System
Rotary Discharge

Figure 4-9. Typical Fabric Filter System

5. The dew point of the flue gas must be considered. An excursion below the dew point can result in condensation and hence blinding of bags. In addition, due to the typically high HCl content of hospital waste incinerator flue gases, condensation can lead to the formation of corrosive HCl acid.

4.3.2 Scrubbers and Dry Injection Systems

Wet scrubbers currently in use offer lower efficiencies for the collection of PM but higher efficiencies for acid gas removal. Wet scrubbers use liquid to remove pollutants from the gas stream. Scrubber design and the type of liquid solution used largely determine contaminant removal efficiencies. Efficiencies for the removal of acid gases with plain water are in the range of 30 percent, while the addition of $Ca(OH)_2$, $CaCo_3$, or CaO to the scrubber liquor has been shown to result in efficiencies of 93-96 percent.[18] In general, high gas-side pressure drops must be used to obtain high efficiencies for PM control.

There are basically three types of wet scrubbers:

(1) low energy (spray tower),

(2) medium energy (impingement scrubbers such as packed column, baffle plate, and liquid impingement), and

(3) high energy (venturi).

Low energy scrubbers (spray towers) are usually circular in cross-section (see Figure 4-10). The liquid is sprayed down the tower as the gases rise. Large particles are removed by impingement on the liquor pool, and finer particles are removed as the flue gas rises through the tower. Low energy scrubbers mainly remove particles in the 5-10 micron range and larger.[19]

Medium energy devices mostly rely on impingement to facilitate removal of PM. This can be accomplished through a variety of configurations, two of which are diagrammed in Figures 4-11 and 4-12.

High energy scrubbers use a venturi mechanism for PM removal (see Figure 4-13). The flue gases impinge on the liquor stream in the venturi section. As the gases pass through the orifice, the shearing action atomizes the liquor into fine droplets. As the gas leaves the venturi

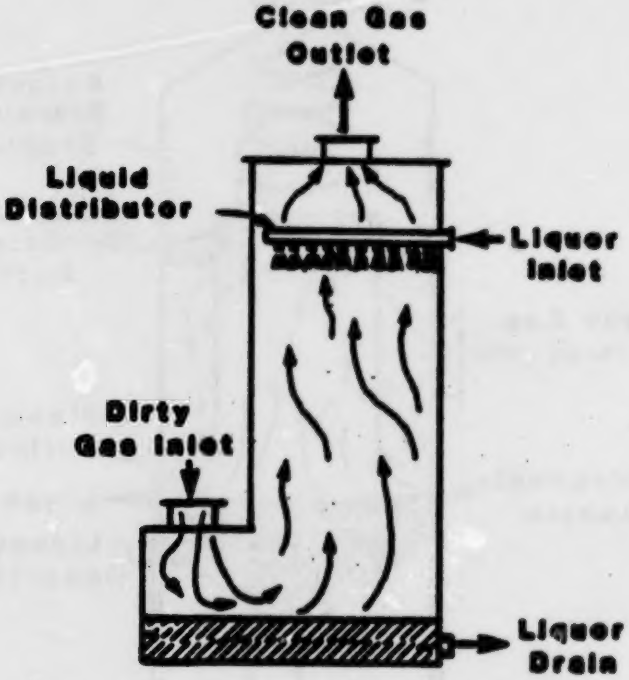

Clean Gas Outlet
Liquid Distributor
Liquor Inlet
Dirty Gas Inlet
Liquor Drain

Figure 4-10. Open Spray Tower Scrubber

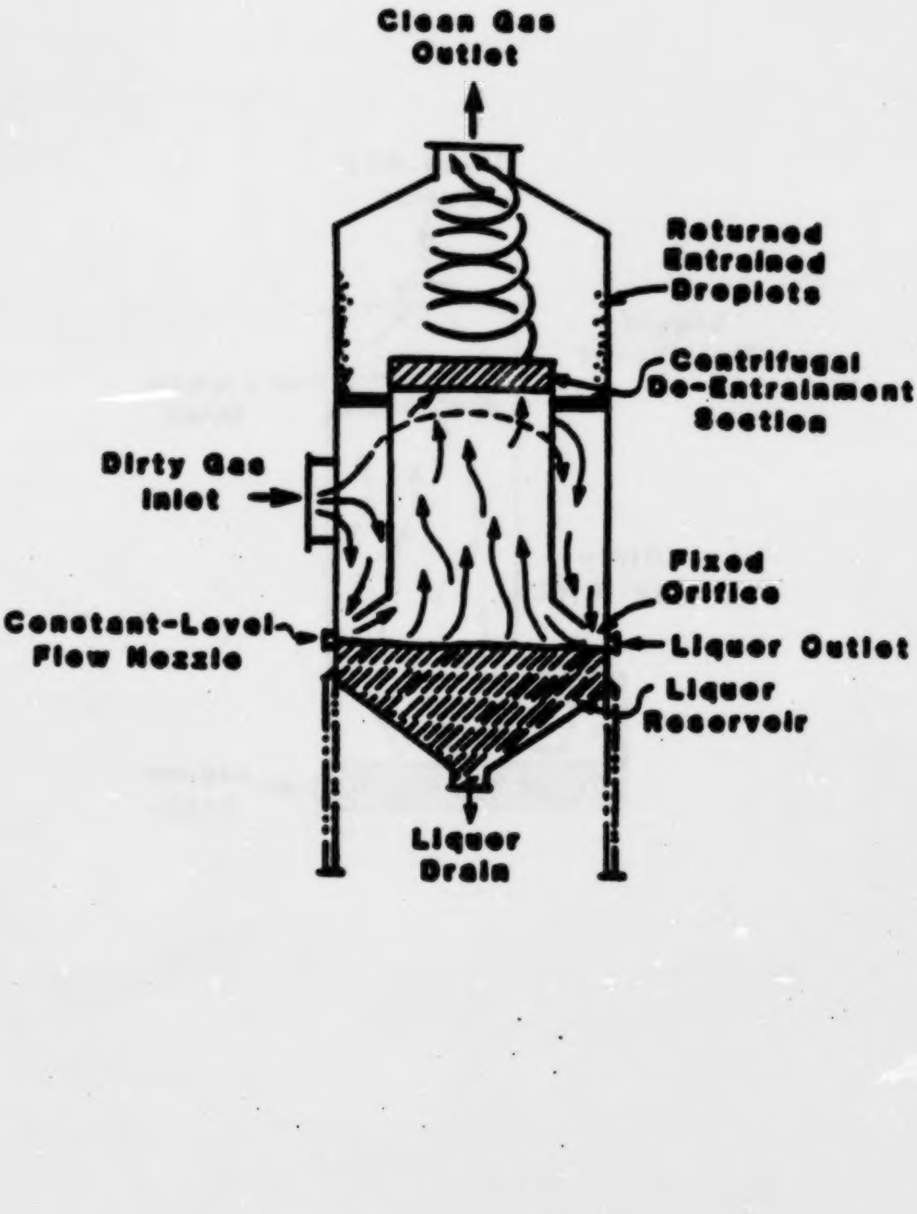

Clean Gas Outlet
Returned Entrained Droplets
Centrifugal De-Entrainment Section
Dirty Gas Inlet
Fixed Orifice
Constant-Level Flow Nozzle
Liquor Outlet
Liquor Reservoir
Liquor Drain

Figure 4-11. Fixed Orifice Scrubber

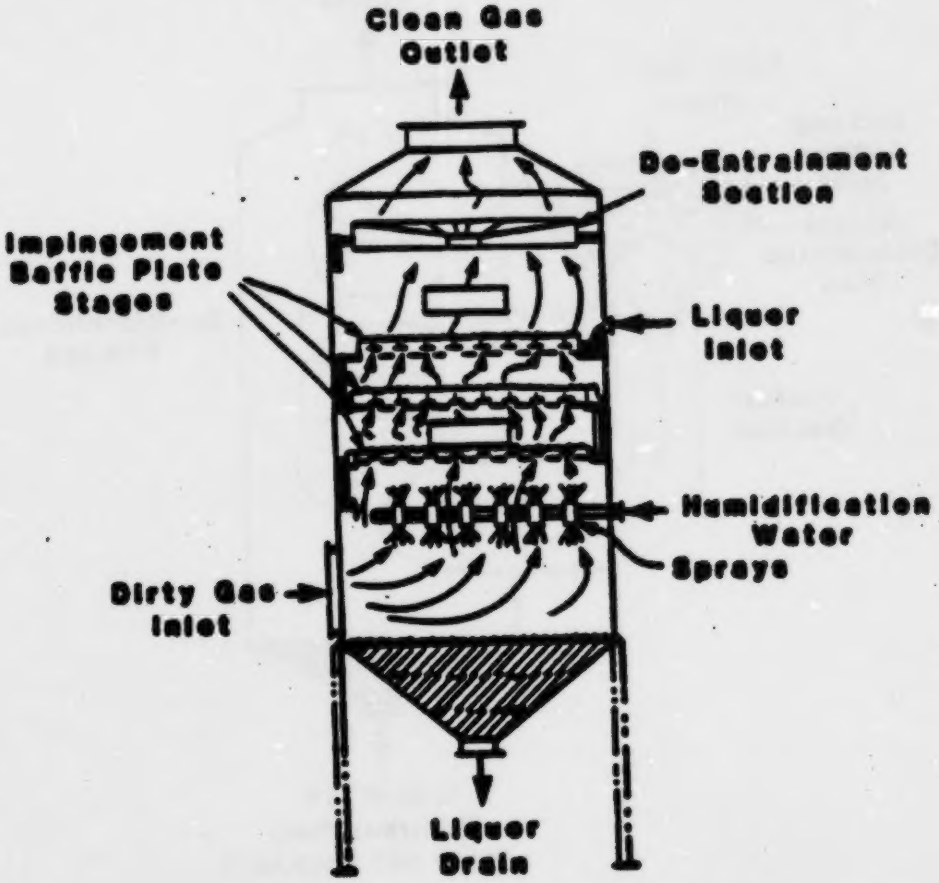

Clean Gas Outlet
De-Entrainment Section
Impingement Baffle Plate Stages
Liquer Inlet
Humidification Water
Sprays
Dirty Gas Inlet
Liquer Drain

Figure 4-12. Baffle Impingement Scrubber

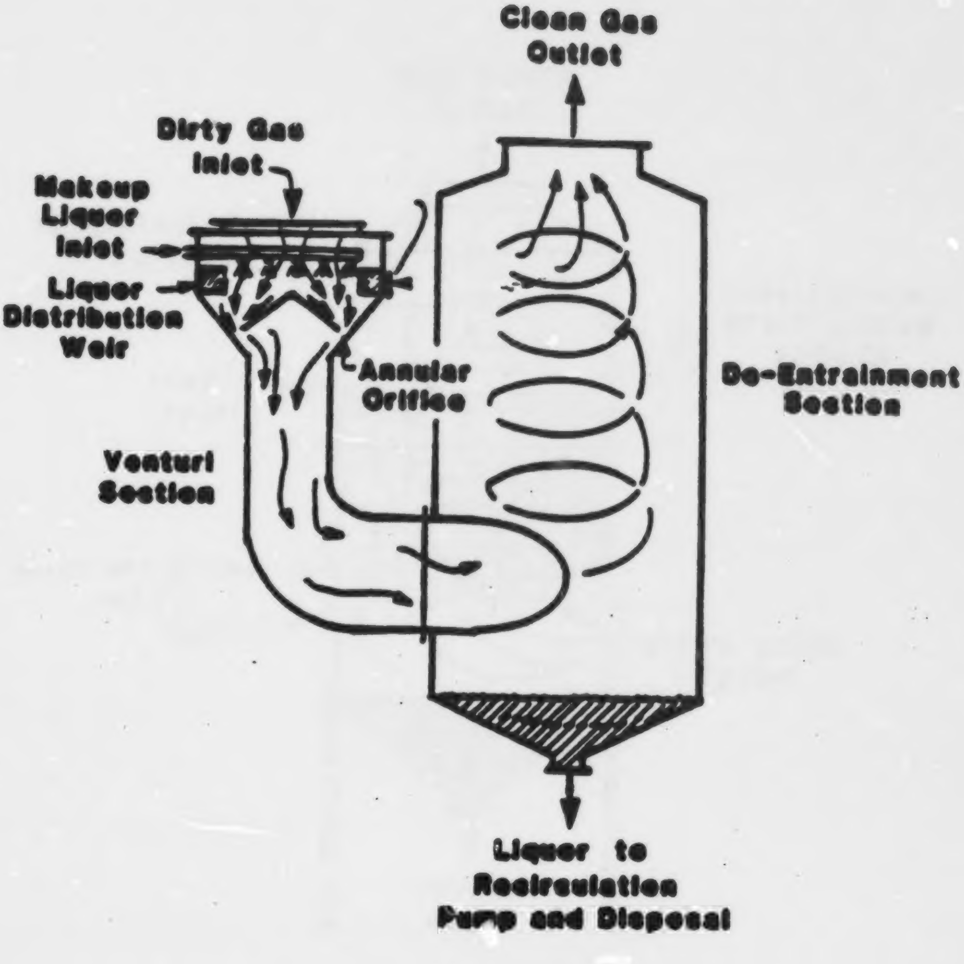

Clean Gas Outlet
Dirty Gas Inlet
Makeup Liquor Inlet
Liquor Distribution Weir
Annular Orifice
Venturi Section
De-Entrainment Section
Liquor to Recirculation Pump and Disposal

Figure 4-13. High Energy Venturi Scrubber

section it decelerates, resulting in further contact between particles and liquid droplets. The droplets are then removed from the device by the centrifugal action in the de-entrainment section.[20]

Like baghouses, wet scrubbers offer both advantages and disadvantages. Some of the major advantages and disadvantages of wet scrubbers are:[21]

Advantages

1. Particle collection and gas absorption can be accomplished simultaneously with proper design.
2. High collection efficiencies can be obtained for any particle size range with sufficient energy input.
3. Viscous materials can be collected without plugging.
4. High temperature gaseous effluent streams can be handled.
5. Moisture content and/or dew point of the effluent gas is not critical to scrubber operation.
6. Heat transfer, chemical reactions, and evaporation are characteristics of wet scrubber operations that can be varied to improve pollutant removal efficiencies.
7. Capital costs are relatively low.
8. Semi-volatile organic collection, such as dioxins and furans. To remove dioxins/furans, an outlet temperature at near 150°C or below is required. Typically, wet scrubber systems quench flue gases between 150 and 200°C.[22] This magnitude of heat loss should reduce the volatile compounds in the flue gas.
9. Trace semi-volatile metal collection, such as arsenic, chromium, and nickel. In general, metal removal efficiencies of wet scrubber systems vary widely between the 11 trace metals listed in Section 3.1.3. A recent emissions test program conducted at a sewage sludge incinerator has shown wet scrubber removal efficiencies greater than 95 percent for chromium, arsenic, and nickel.[23] Furthermore, it was shown that 50 percent of the cadmium was scrubbed from the gas stream while an average of 40 percent of the lead was removed.

Disadvantages

1. High energy input is required for collection of the finer dust particles.
2. Corrosion and erosion are characteristic of all wet processing.

3. An effluent liquor disposal system is required.

4. Discharge of a water-saturated gas stream can produce a visible steam plume.

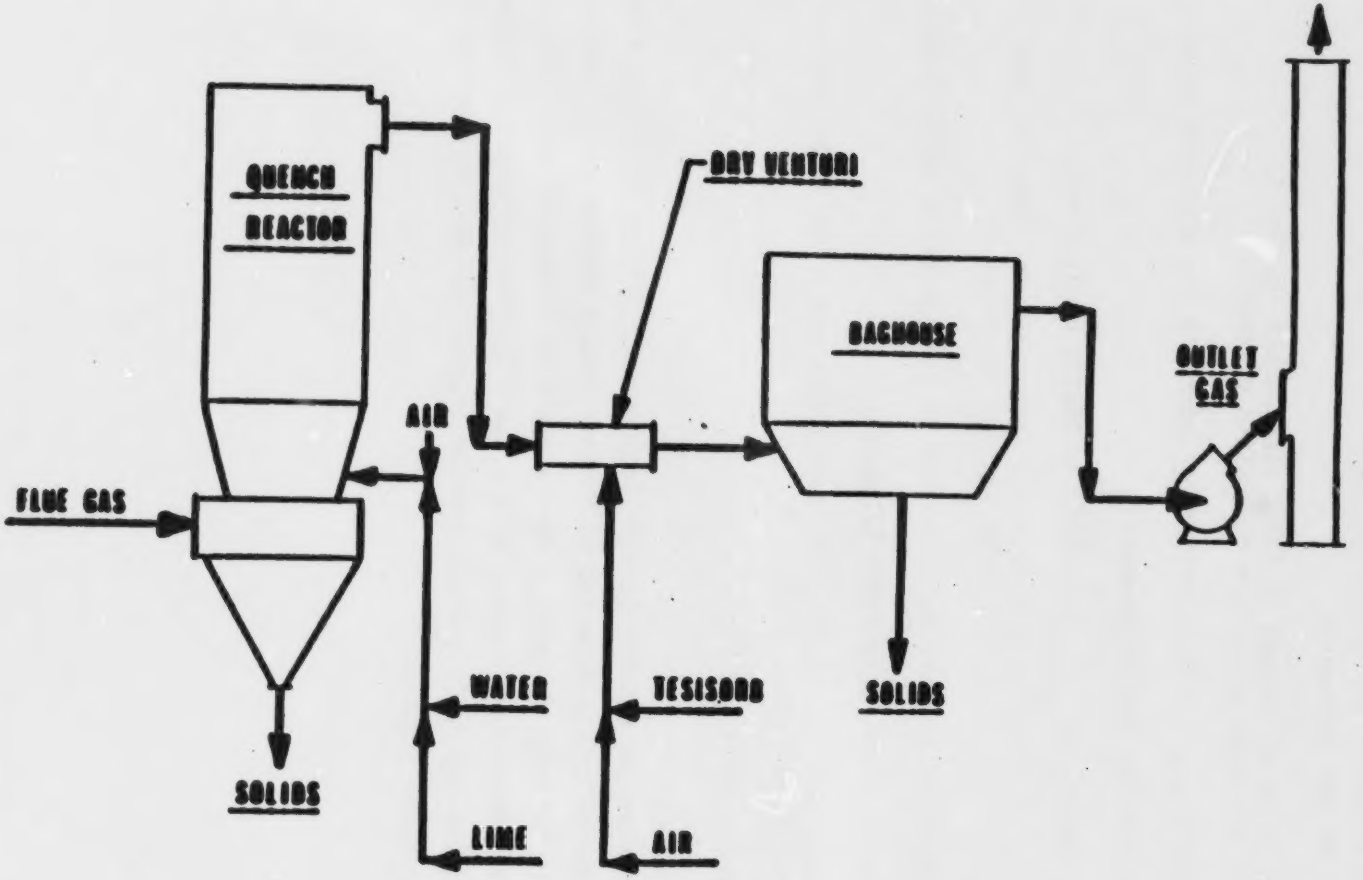
5. Re-entrainment of PM may be a problem.

6. Wet scrubbers are not effective for control of insoluble gaseous organics.

Dry scrubbers combined with fabric filters applied to MSW incinerators have received considerable attention recently. In these systems, a lime slurry is injected into the scrubber where it contacts the flue gas. The water is evaporated and dry salts result from the reaction of lime with constituents of the flue gas. The salts, unreacted lime, and particulate matter are collected in fabric filters downstream of the reactor. It has been theorized that filter cake build-up provides available reaction sites for continued reaction with pollutants from the flue gas.

Test results from MSW incinerators for dry scrubbing/fabric filter systems show enhanced PM emission reduction in all particle size ranges compared to wet scrubbers operating with even larger pressure drops. Acid gas and metal removal efficiencies have also been high.[24-28] Also of interest are the low dioxin/furan emissions from the dry scrubbing system.

A diagram of a commercially available dry injection system, the Teller system, is shown in Figure 4-14.[29] In this system a dry venturi is located between the dry scrubber (quench reactor) and the baghouse. The dry venturi reportedly causes agglomeration of small particles formed in the dry scrubber which results in reduced pressure drop in the baghouse. This reduced pressure drop translates to longer cleaning cycles which are associated with higher removal efficiencies for small particles. The Teller system employs a lime slurry in the quench reactor for acid gas absorption and a proprietory dry crystalline product (called Tesisorb) in the dry venturi to promote capture and agglomeration of sub-micron particles. Other dry injection systems applied to MSW incinerators utilize only pulverized lime injected into the flue gas stream in a dry venturi upstream of a baghouse.


QUENCH
REACTOR
DRY VENTURI
BAGHOUSE
OUTLET
GAS
AIR
FLUE GAS
WATER
TESISORB
SOLIDS
SOLIDS
LIME
AIR

Source: Reference 29

Figure 4-14. Teller Dry Scrubbing System

Advantages cited for dry scrubbing/injection followed by fabric filtration include the following:

(1) Insensitive to changes in inlet particulate loading or characteristics within the combustion chamber.

(2) Effective and efficient particle capture in the submicron range.

(3) Efficient SO_2 and HCl removal.

(4) Produces dry particulates that can easily be disposed.

(5) Because flue gas is not saturated with moisture, there is less potential for a visible plume exiting the stack.

(6) Reduction of organic emissions due to low operating temperatures.

Disadvantages cited include the following:

(1) Reduced exit gas temperatures can affect gas plume rise, thus affecting pollutant dispersion.

(2) Reagents costs are high.

4.3.3 Afterburners

A third combustion chamber on some incinerators acts as an afterburner. This control device can be expected to further reduce organic emissions. The most likely location for such a device would be before the scrubber. Direct flame afterburners operating at a 2,000°F temperature and 1.0 second residence time can typically achieve greater than 98 percent destruction even for chlorinated organics.[30]

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5.0 REGULATORY STATUS AND STRATEGIES

Regulatory strategies in the United States to control air emissions from hospital waste incinerators have not been addressed to date at the Federal level but have been a focus of attention at the State level. Because of their relatively small size, emissions from hospital waste incinerators are not subject to Federal regulations which control emissions from larger MSW incinerators and solid waste-fired boilers. Instead, hospital waste incinerators are subject to a "patchwork quilt" of State and local guidance and regulations. Currently, most States recommend, but do not require, the control of particulate matter (PM) emissions and opacity for hospital waste incinerators. However, with the growing public concern over handling and disposal of hospital wastes, several States have developed emission limit regulations for incinerators which have recently been promulgated or are now in the proposal stage.

This section discusses the current regulatory environment for hospital waste incinerators at both the Federal and State level. The information presented on State programs is accurate as of June 1988. However, due to the rapidly changing nature of these programs, this information is expected to become quickly out-of-date.

In addition to Federal and State regulations in the United States, this section also reviews regulations which have been established for hospital waste incineration in Canada and European countries.

5.1 FEDERAL REGULATIONS AND PROGRAMS

5.1.1 New Source Performance Standards

Hospital waste incinerators are not currently a source category subject to New Source Performance Standards (NSPS). However, they would be subject to the NSPS for industrial, commercial, and institutional steam generating units (i.e., boilers) at 40 CFR Part 60 Subpart Db if units have a heat input capacity above 100 million Btu/hr and recover heat to generate steam or to heat water (or other heat transfer media). At 8,500 Btu per pound of

Type 0 (see Table 1-3) waste, a hospital incinerator must be sized to feed over 11,700 lb/hr of waste to be subject to the boiler NSPS. The largest system offered for on-site hospital waste incineration is approximately 6,000 lb/hr capacity, and most units are well below this size. Hence hospital waste incinerators are unlikely to be impacted by the current boiler NSPS.

EPA is currently evaluating NSPS for smaller boilers with capacities below 100 million Btu/hr. The lower size cutoff is one of the factors to be determined during the rulemaking process. A lower size cutoff below 50 million Btu/hr would affect at least a fraction of new, modified, or reconstructed hospital waste incinerators. The pollutants being evaluated for the small boiler NSPS are PM, opacity, NO_x, and SO_2. Proposal of this standard is scheduled for June 1989.

NSPS limiting PM emissions to 0.08 gr/dscf (equivalent to about 0.18 lb/million Btu) corrected to 12 percent CO_2 have been promulgated at 40 CFR Part 60 Subpart E for incinerators having a design capacity of 50 ton/day (i.e., 4,167 lb/hr) or greater and which burn more than 50 percent municipal type waste. This waste is defined as "waste consisting of a mixture of paper, wood, yard wastes, food wastes, plastics, leather, rubber, and other combustibles, and noncombustible materials such as glass and rock." Although hospital waste would seem to qualify under this definition, the size limit for Subpart E would apply to only the largest of hospital waste incinerators.

5.1.2 National Emission Standards for the Hazardous Air Pollutants

Of the 12 NESHAPs promulgated pursuant to Section 112 of the Clean Air Act which address hazardous pollutants, none pertain to hospital waste incinerators.

5.1.3 Resource Conservation and Recovery Act Requirements

As a first step in fulfilling the Congressional mandate to establish a hazardous waste management system, EPA published proposed regulations in the Federal Register on December 18, 1978, which included a proposed definition and treatment methods for infectious waste.[1] During the public comment period for this rulemaking, EPA received approximately sixty comments which specifically addressed the infectious waste provisions of the proposed regulations.[2]

On May 19, 1980, EPA published the first phase of the hazardous waste regulations. The Agency stated in the preamble to the regulations that the sections on infectious waste would be published when work on treatment, storage, and disposal standards was completed. Recently, EPA published a Federal Register notice of data availability and request for comment on issues pertaining to infectious waste management.[3]

5.1.4 Prevention or Significant Deterioration Requirements

Hospital waste incinerators are not among the 28 named prevention of significant deterioration (PSD) source categories. Even though waste generation rates vary among hospitals, emissions from incinerators are typically less than 250 tons per year. Therefore, in most states best available control technology (BACT) is not required for emitted pollutants.

5.2 STATE REGULATIONS AND PROGRAMS

5.2.1 State Requirements for Waste Handling

Most states have requirements for licensing of hospital that may include general requirements for infectious waste disposal. Usually, these general requirements are limited in scope and do not apply to other sources of infectious waste, such as crematoria.[4] The only restriction on the pathological or biomedical waste incinerators in many states is that they not create a public nuisance. That has meant that no odors are to be generated and that the opacity is to be low.[5]

A majority of states have passed hazardous waste legislation to control the treatment, storage, and disposal of infectious waste (as part of their hazardous waste program). Some states have already promulgated regulations controlling infectious waste, while other states are preparing such regulations. Since there is no unanimity of opinion on the hazards posed by infectious waste and appropriate techniques for safe disposal of these wastes, state control varies.[6] Most states do not have specific requirements for hospital incineration that limit air pollutant emissions.

To determine what efforts different states have taken to regulate infectious wastes, the National Solid Wastes Management Association's (NSWMA) Infectious Waste Task Force surveyed the state health and environmental agencies in January 1987. The general purpose of the survey was to determine where treatment and disposal of infectious waste are subject to regulations distinct from those that apply to municipal solid waste (MSW).[7] The survey's results indicated the following:[8]

- The solid waste and/or health departments in 28 states do define infectious waste items and subject these items to special rules or recommendations in management.
- Some states such as Massachusetts and Louisiana expect to revise their definitions soon to capture all generators of infectious wastes and not just hospitals.
- In general, hospitals and health-care facilities are prevented from disposing of wastes in a landfill without rendering the wastes non-infectious.
- Thirteen states have written or endorsed specific guidelines or requirements for transporting untreated infectious wastes.

5.2.2 State Air Emission Requirements

Radian has contacted several states to clarify their infectious waste management requirements; the information collected from the states is presented in Appendix A. The appendix contains an updated list of infectious waste regulations and requirements as well as a list of state offices that may be contacted for additional information. Where data were missing from non-contacted states, data available from the EPA Guide for Infectious Waste Management were listed. Most states did not list a specific regulation concerning the incineration of hospital or infectious waste.

Pennsylvania has recently established best available control technology guidance for hospital infectious waste incineration. These guidelines require stack emission limitations on particulate matter, carbon monoxide, hydrochloric acid and visible air contaminants. The guidelines are listed in Table 5-1 along with guideline emission limits set by New York, New Jersey, Connecticut, and Illinois.

5.2.3 State Air Toxics Programs

A majority of states and localities use some form of ambient guidelines or standards for the control of toxic air emissions from hospital incinerators. Several states regulate new hospital waste incinerators in a manner similar to that required by the Resource Conservation and Recovery Act (RCRA) hazardous waste incineration regulations, i.e.; 100 ppm CO, 90% control or 4 lb/hr HCl emissions, and 0.08 gr/dscf (corrected to 12 percent CO_2) for particulates.[9] The city of Philadelphia is requiring that new hospital incinerators have scrubbers, which are used to control acid gases and toxic air contaminants.[10]

The State of Pennsylvania also requires ambient impact analyses for arsenic, cadmium, hexavalent chromium, lead, mercury, nickel, polychlorinated dibenzo-p-dioxins, and polychlorinated dibenzofurans. The acceptable ambient air concentrations for these pollutants are listed in Table 5-2. Stack sampling is required to demonstrate compliance with ambient limits based on dispersion modeling calculations.

The State of New York has drafted operating guidelines for hospital waste combustion. These guidelines require stack emission limitations for particulate matter, carbon monoxide, hydrochloric acid, and visible air contaminants. Also, continuous monitoring and recording of temperature in the secondary chamber are required to show an exit temperature of at least 1800°F. In addition, the State requires demonstration of compliance with acceptable ambient air quality levels for toxic air contaminants (or acceptable risk assessments for carcinogens) under its Air Guide policy (see Table 5-2).[11,12]

In the State of California each local air quality district can establish its own emission limit requirements. Presently, guidelines on emission limits MSW and hazardous waste facilities are serving as guidelines for hospital waste incineration. However, California is in the process of developing new restrictions that pertain directly to hospital waste incineration.

TABLE 5-1. GUIDELINE EMISSION LIMITS FOR INCINERATORS BURNING HOSPITAL WASTE[a]

State/Facility	Pollutant				
	Particulate Matter	Opacity	HCl	CO	SO_2
New York	0.015 gr/dscf (at 7% CO_2)	maximum continuous 6-minute average <10%	50 ppmv 3-hour average or shall be reduced by 90% or uncontrolled rate less than 4 lb/hr for facilities below 580 lb/hr total charging rate	100 ppm hourly average (at 7% O_2	--
Pennsylvania (Facility with capacity ≤500 lb/hr)	0.08 gr/dscf (at 12% CO_2)	<30% at all times; maximum 3-minute average <10% in any hour	<4lb/hr or shall be reduced by 90% by weight	100 ppmv hourly average (at 7% O_2)	--
Pennsylvania (Facility with capacity >500 lb/hr, ≤2000 lb/hr)	0.03 gr/dscf (at 7% O_2)	<30% at all times; maximum 3-minute average <10% in any hour	30 ppmv hourly average (at 7% O_2) or shall be reduced by 90% by weight	100 ppmv hourly average (at 7% O_2)	30 ppmv hourly average (at 7% O_2) or shall be reduced by 75% by weight
Pennsylvania (Facility with capacity >1000 lb/hr)	0.015 gr/dscf (at 7% O_2)	<30% at all times; maximum 3-minute average <10% in any hour	30 ppmv hourly average (at 7% O_2) or shall be reduced by 90% by weight	100 ppmv hourly average (at 7% O_2)	30 ppmv hourly average (at 7% O_2) or shall be reduced by 75% by weight
New Jersey	0.02 gr/dscf (at 12% CO_2)	--	--	--	--
Connecticut	0.02 gr/dscf (at 12% CO_2)	--	--	--	--
Illinois (Facility with capacity >6000 lb/hr)	0.05 gr/scf (at 12% CO_2)	30%	--	--	--
Illinois (Facility with capacity >2000 lb/hr, <6000 lb/hr)	0.08 gr/scf (at 12% CO_2)	30%	--	500 ppm at 50% excess air	--
Illinois (Facility with capacity <2000 lb/hr)	0.1-0.20 gr/scf (at 12% CO_2)	30%	--	--	--

[a] References 21-25.

TABLE 5-2. ACCEPTABLE ANNUAL AMBIENT CONCENTRATIONS REPORTED FOR SELECTED POLLUTANTS[a]

Metal/Compound	Pennsylvania	New York
Arsenic and Compounds	0.23×10^{-3}	0.67
Beryllium and Compounds	0.42×10^{-3}	-
Cadmium and Compounds	0.56×10^{-3}	2.0
Hexavalent Chromium and Compounds	0.83×10^{-4}	0.167
Lead and Compounds	0.50	1.5[b]
Mercury and Compounds	0.08	0.167
Nickel and Compounds	0.33×10^{-2}	3.3
PCDD and PCDF[c]	0.30×10^{-7}	-[d]

[a] References 26 and 27; all concentrations in ug/m^3.

[b] Federal standard for lead; not yet officially adopted by New York State, but currently being applied to determine compliance status.

[c] Expressed as tetrachlorinated dibenzo-p-dioxin equivalents

[d] Emission sources of chlorinated dibenzofurans and dibenzodioxins are reviewed on a case-by-case basis by the Department of Health (DOH). The NY State DOH has determined that basing an acceptable ambient level on TCDDs does not adequately represent public health risks for the dioxin compounds.

5.2.4 State Permitting Requirements

Radian contacted several states with relatively stringent air emission limitations to discuss procedures and analyses required to obtain an operating permit for an infectious waste incinerator. The objective of this effort was to identify the range of analyses and requirements currently associated with the permitting process. Operator training and ash disposal requirements are also addressed, where applicable. The results of the contacts are summarized below, by state, in alphabetical order:

Connecticut - Department of Environmental Protection[13]

- Infectious wastes are currently regulated as special wastes.
- BACT analysis is required in lieu of emission limits for any pollutant emitted at rates greater than 5 tons/year. This includes HCl, PM, and toxics.
- Ambient impact/risk analysis are not required, although stack emissions are limited to levels dictated by ambient Hazard Limiting Values (HLV) at the facility fenceline. The HLVs are based on the State's air toxics control program.
- Incinerator ash is evaluated using the Extraction Procedure (EP) toxicity test. If the ash fails the test, it must be handled as a hazardous waste. If the ash passes the test, which is more common, it is sent to a permitted special waste landfill. The ash must be isolated and contained in a separate cell at the landfill.

Illinois - Environmental Protection Agency[14]

- No BACT or ambient impact analyses are required unless the source qualifies under Federal PSD rules.
- Infectious waste incinerator ash is treated as a hazardous waste. It must be sent to a permitted special waste landfill. The ash must be shipped in accordance with the State's manifest system.
- If the waste is to be incinerated, the permit applicant must describe the incinerator to be used; wastes to be incinerated; gas cleaning devices; methods to dispose of bottom ash, fly ash and/or scrubber sludge; and indicate operating temperatures and gas residence time.

Massachusetts - Division of Air Quality Control[15]

- A BACT analysis is required for all infectious waste incinerators. Emissions of concern include PM, PM_{10} acid gases, dioxins, furans, pathogens, and metals. The analysis is performed from a "top-down" perspective (i.e., the most stringent technology applicable must be examined and rejected on the basis of costs or other factors before less stringent alternatives can be considered).

- In addition to the BACT analysis results, permit applicants must specify procedures for incineration warm-up, burn-down, feed charging, and waste handling which meet State requirements. For example, infectious waste must be placed in boxes prior to disposal.

Michigan - Department of Natural Resources[16]

- Applicants for a permit to operate must submit a complete description of the incineration and potential pollution control equipment which includes the following:

  -Plot plan and nearby building information

  -Description of the incinerator

  -Description of the waste stream

  -Operating schedule

  -Temperature profile and retention time

  -Temperature monitoring and recording system

  -Procedures to insure that prescribed temperatures are monitored

  -Flue gas volume and composition

  -Description of combustion controls

  -Discussion of the physical and economic feasibility of installing and operating an acid gas scrubbing system and a high efficiency particulate collector

  -Description of proposed emission control equipment

  -Description of emission control equipment by-pass, if applicable

  -Discussion of stack sampling ports

  -Description of ash handling system

  -Description of preventative maintenance and malfunction abatement system

-Maximum uncontrolled and controlled emission rates for specified pollutants

-Demonstration that the proposed emissions will not cause injurious effects to human health and safety

- In lieu of their own emissions data, applicants may use the DNR's statistical emission rate data (95th percentile) compiled on the basis of available test data.

- To demonstrate that emissions do not cause injurious effects to human health and safety, applicants must perform dispersion modeling and determine ambient concentrations at both ground level and air intake levels for nearby buildings. Acceptable ambient air concentrations have been established for the following pollutants:

  -Particulate matter

  -Sulfur dioxide

  -Nitrogen oxides

  -Carbon monoxide

  -Polychlorinated biphenyls

  -Mercury

  -Arsenic

  -Cadmium

  -Chromium

  -Total polychlorinated dibenzo-p-dioxins (PCDD)

  -Total polychlorinated dibenzofurans (PCDF)

  -Hydrogen chloride

  The applicant may request the DNR to perform the necessary dispersion analysis using the methods developed by the Michigan Air Pollution Control Commission.

- As discussed, ambient pollutant concentrations must be below acceptable levels at both ground and air intake levels. Options to remedy predicted concentrations above required levels are to increase stack height and to install emission control equipment such as scrubbing systems and baghouses.

New York - Department of Environmental Conservation[17]

- Applicants must submit engineering data relative to waste characterization, incinerator design, combustion air systems, incinerator control devices, and flue gas cleaning devices.

- An ambient air quality impact analysis must be performed with respect to the following pollutants:

  -Total particulates

  -Sulfur dioxide

  -Nitrogen dioxide

  -Carbon monoxide

  -Hydrocarbons

  -Hydrogen chloride

  -Lead

  -Cadmium

  -Chromium

  -Arsenic

  -Mercury

  -Nickel

  -Polycyclic aromatic hydrocarbons

  -Polychlorinated biphenyls

  -2,3,7,8 tetrachlorinated dibenzo-p-dioxins (TCDD)

  -Total TCDD

  -Total PCDD

  -Total PCDF

Pennsylvania - Department of Environmental Resources[18]

- Ambient impact analyses must be conducted for: a) arsenic and compounds; b) beryllium and compounds; c) cadmium and compounds; d) hexavalent chromium and compounds; e) lead and compounds; f) mercury and compounds; g) nickel and compounds; h) PCDD and PCDF expressed as 2,3,7,8 TCDD equivalents using toxicity equivalents factors (TEF). Using available emission factors, the emissions from the facility must be estimated and the analyses must be conducted by performing dispersion modeling using the facility's exhaust characteristics.

- If the application is subject to "Prevention of Significant Deterioration" (PSD) requirements, the analyses shall be conducted in accordance with the "Guidelines on Air Quality Modeling" dated January 1983 (as revised). The applicant is advised to discuss the modeling requirements with the Department prior to starting any modeling study. The analysis must show that predicted concentrations do not exceed the levels shown in Table 5-2.

- Compliance must be verified by stack sampling. Using the actual stack emission rates, the exhaust parameters from each test and the dispersion modeling techniques specified in the application as approved by the Department, the calculated maximum annual ambient concentrations must not exceed the stated levels.

- Incinerator ash must be landfilled. The landfill must be permitted by the Department to accept such wastes. By the end of the decade, the Department intends that only landfills that meet new municipal waste disposal regulates, similar to these for hazardous waste landfills, continue to operate.

- An application for disposal of special waste must be filed and approved which includes a detailed description of the type and source of waste and of the incinerating conditions. The Department requires ash to be tested under conditions that simulate a landfill and may, if necessary, impose special disposal conditions in a permit to prevent loading of heavy metals.

- Before construction, hospital waste incinerators must undergo a plan review in which the Department reviews the design to insure that all applicable standards are capable of being met. The plan approval application must include a description of each specific waste and approximate quantity of each such wastes which will be charged to the incinerator. The application must, as a minimum, contain the final design specifications of the incinerator and the associated air pollution control devices with dimensioned drawings indicating the locations of burners, air injection ports and monitors.

- In addition to emission estimates and the results of the ambient impact analyses, the plan must include a set of calculations for estimating secondary chamber residence times using specified procedures.

- Facilities capable of burning hospital/infectious wastes at rates greater than or equal to 50 tons per day must also meet the permitting criteria established for municipal waste incinerator.

- Prior to startup, all incinerator operators must be trained as to proper operating practices and procedures. The content of the training program must be submitted to the Department for approval. The applicant must submit a copy of a certificate verifying the satisfactory completion of a training program by all operators prior to issuance of an operating permit.

5.3 FOREIGN REGULATIONS

In Canada, air pollution regulations are established by each provincial government. Table 5-3 lists emission limits established in Alberta, Canada and technical requirements established in several European countries. This study did not include the investigation per se of foreign procedures or regulations. However, the data presented in Table 5-3 were extracted from References 19 and 20.

TABLE 5-3. FOREIGN EMISSION REGULATIONS FOR HOSPITAL WASTE[a]

Pollutant	Alberta, Canada	European[a]
Particulate matter	0.20 kg/1000 kg of gaseous effluent[b]	200 mg/Nm^3 dry at 7% CO_2 maximum
	0.60 kg/1000 kg of gaseous effluent[c]	--
HCl	100 ppm at 50% excess air	300 mg/Nm^3 dry at 7% CO_2 maximum
CO	--	500 mg/Nm^3 dry at 7% CO_2 maximum
SO_2	--	200 mg/Nm^3 dry at 7% CO_2 maximum
HF	--	5 mg/Nm^3 dry at 7% CO_2 maximum
Opacity	--	Not to exceed 30%

[a] References 19 and 20.

[b] For incinerators with a capacity of greater than 227 kg/h.

[c] For incinerators with a capacity of less than 227 kg/h.

5.4 REFERENCES

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6.0 HOSPITAL WASTE INCINERATOR MODEL PLANTS

One of the objectives of this study was to develop modeling parameters emissions and exposure from hospital incinerator units. The parameters developed in this study will be used in EPA's Human Exposure Model (HEM). Results of the HEM analysis will then be used to provide a preliminary estimate of chronic exposure to emissions from hospital waste incinerators. This objective was accomplished by developing input data for model incinerators which are felt to be representative of the general population instead of using actual hospital incinerator sites and stack parameters. This approach was taken because of the difficulty involved in characterizing the capacity and location of all hospital incinerators on a national level.

The approach used was to analyze a segment of the population for which detailed information could be obtained regarding unit capacity, stack parameters, and operation. In this case, a recent database of hospital incinerators in the State of New York was located during the study and used as a population segment. Through analysis of the distribution of incinerator capacities in the New York population, model plants were identified. The appropriate stack parameters (height, diameter, gas velocity, and temperature) were then determined by further evaluation of this data set. Finally the emissions factors of Section 3.0 were applied to to these model plants to estimate the short-term and long-term emissions rates.

This section contains a brief discussion of the relationship between hospital populations and incinerator populations. Next, the model incinerator capacities and stack parameters selected for the analysis are presented. Finally, the corresponding emissions rates for pollutants of concern are presented for the model plants, based on the emissions data from Section 3.

6.1 POPULATION CHARACTERISTICS

6.1.1 Population Distribution

As noted in Section 1.1, there are currently over 6,000 hospitals in the U.S.; it is estimated that over 90 percent of these facilities operate incinerator equipment of some kind, if only a small retort-type unit. The population of controlled air incinerators is smaller but still substantial. The development of a national inventory of hospital incinerators was not feasible for this study. Instead, an analysis of a subset of the population for which the necessary information was available was performed. A recent New York (NY) State database was located during the study which contained information gained through an in-state survey of incinerator units.[1] This database contained unit size, location, annual operation, and stack parameters for 433 incinerators located in NY.

To estimate the "representativeness" of the NY hospital population relative to the U.S. population, the distribution of hospital sizes was examined. The distribution of hospital sizes according to bed number is presented for both NY and the U.S. in Figure 6-1.[2] Both these distributions have similar shapes for hospital sizes between 0 and 500 beds. However, there is a greater proportion of hospitals above the 500 bed size in NY than in the U.S. population. This is probably due to the fact that NY has several densely populated areas. Therefore, a model incinerator capacity which corresponds to hospitals with greater than 500 beds was selected to model hospitals in densely populated areas in the U.S. The potential impact of these larger incinerator units on the associated populations will likely be of interest to EPA.

No information was found during this study which relates hospital size to the use of incineration or to incinerator capacity. Therefore, a correlation between hospital size and incinerator capacity could not be developed. A study of the population distribution of incinerator units within the NY incinerator database was, therefore, undertaken. Figure 6-2 presents the results of this investigation. As shown, 59.6 percent of the population are units with design feed capacities of less than 200 lb/hr. A model incinerator was, therefore, chosen from within the less than 200 lb/hr capacity range.

A further breakdown of the smaller size incinerator population in NY by unit capacity is shown in Figure 6-3. As can be seen, this population is bimodal with peaks for units between 50 and 74 lb/hr and 100 and 124 lb/hr. A detailed analysis of these two size ranges reveals that the majority of units in each of the ranges are 50 and 100 lb/hr, respectively. Since a

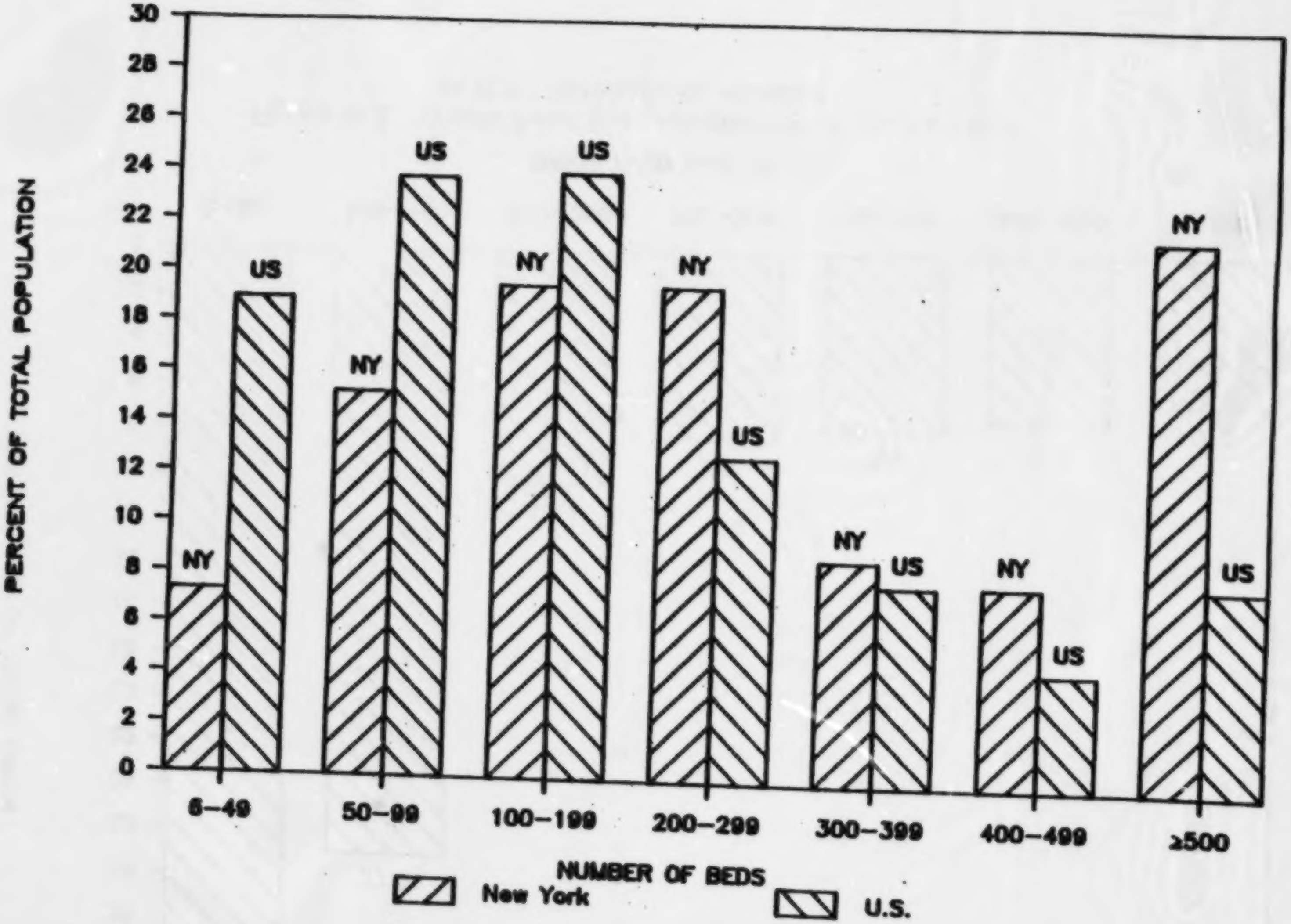

Figure 6-1. Distribution of Hospital Sizes According to Bed Number

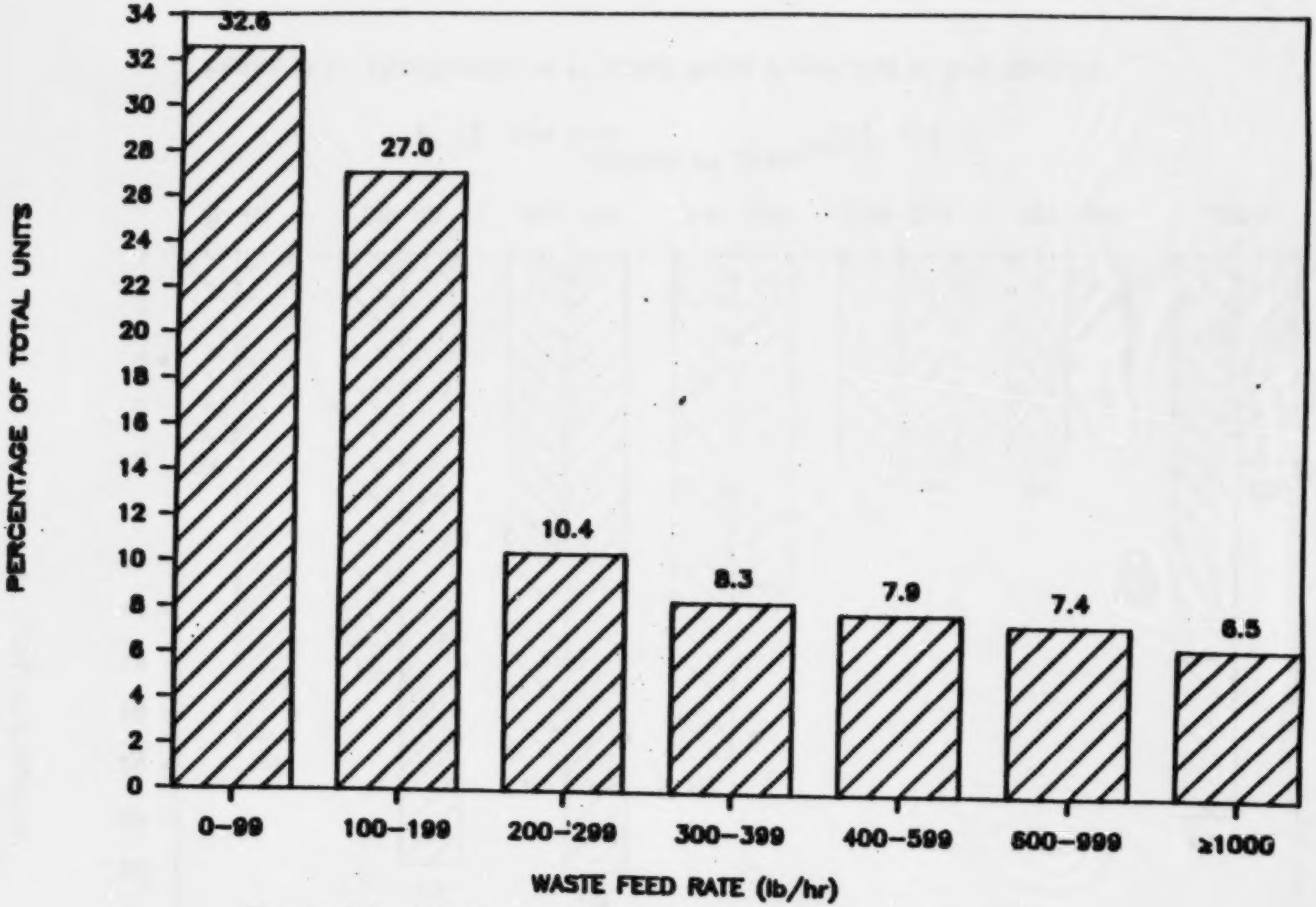

Figure 6-2. Waste Feed Rate Distribution of Incinerators in N.Y. Database by Number

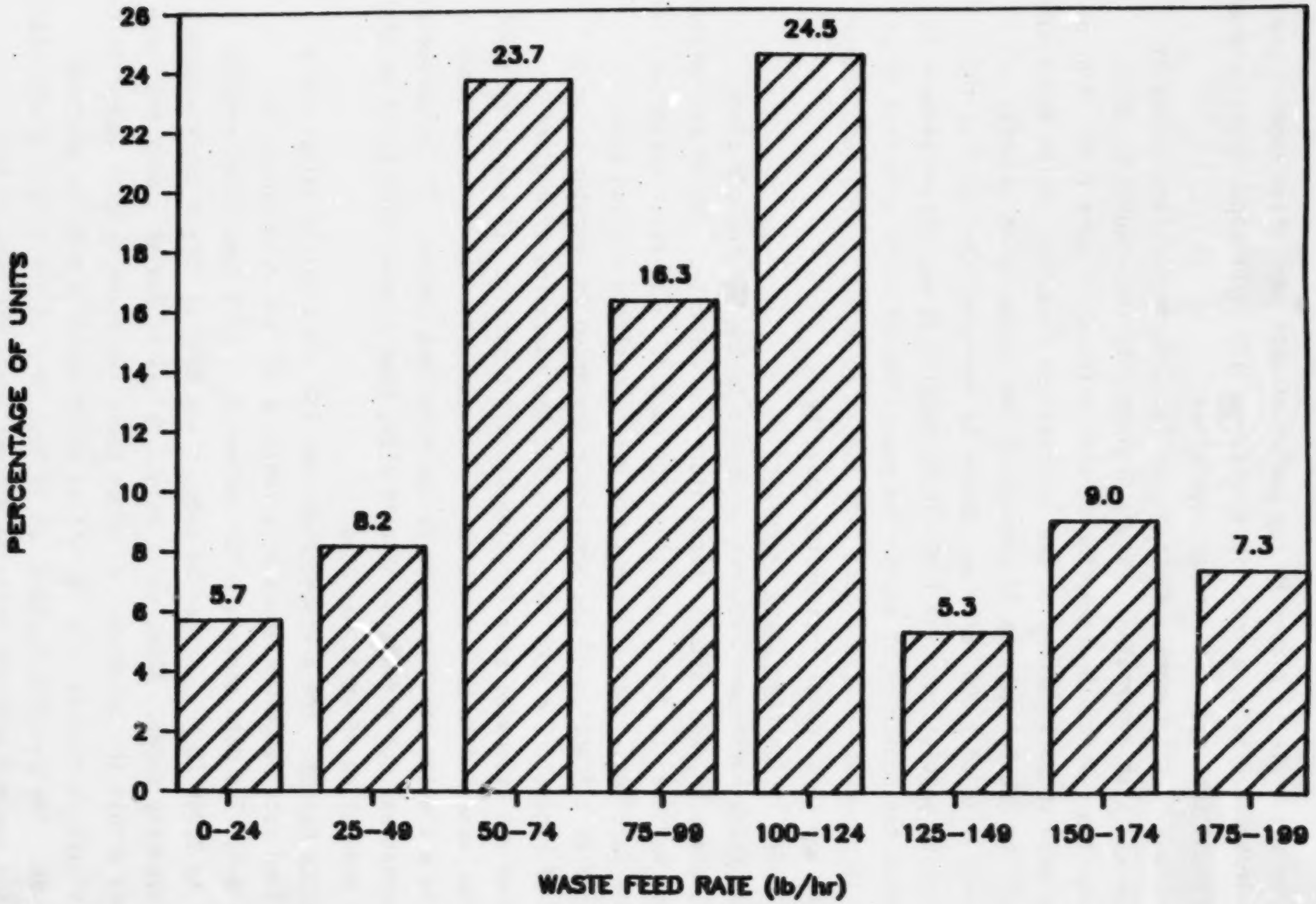

Figure 6-3. Waste Feed Rate Distribution of Small (Less Than 200 lb/hr) Incinerators in N.Y. Database by Number

100 lb/hr feed rate is closer to the median of this population segment than the 50 lb/hr feed rate, a model incinerator of 100 lb/hr capacity was chosen to represent the small incinerator population.

A study of the capacity distribution for the incinerators in the NY database was also undertaken. Figure 6-4 presents the results of this investigation. As can be seen, incinerator units which burn 1,000 lb/hr or greater make up 33.5 percent of the incineration capacity. Units which burn 600 lb/hr or greater make up 52 percent of the incineration capacity. A model unit size of 1,000 lb/hr was chosen to represent this half of the incineration population. The 1,000 lb/hr model size was chosen because it represents the median point within the population of units with feed rates of 600 lb/hr or above (see Figure 6-2) and is an order of magnitude greater than the 100 lb/hr model incinerator capacity.

6.1.2 Model Incinerator Stack Parameters

The stack parameters required as inputs to the HEM include stack height, diameter, and exit gas temperature and velocity. The NY incinerator database was used to determine values for each of these stack parameters for modeling purposes. The approach taken was to evaluate a given stack parameter as a function of the previously presented incinerator capacity ranges of Figure 6-2. From this analysis, the variation of a given parameter was evaluated as a function of unit capacity. If the given stack parameter appeared to be a function of unit capacity, then a value based on units in a similar capacity range to the model was chosen. If the parameter of interest was not a function of unit size, then a mean value based on the entire population of units was used.

Stack Height. The average, high, and low stack height values for a given feed rate range are shown as a function of feed rate ranges in Figure 6-5. The data shown are for incinerators with feed rates ranging from 1 to 2,700 lb/hr. As can be seen, stack heights vary greatly within a given capacity range. Also, stack height values as low as 6 to 8 feet were observed within the database. Although these low stack heights appear to be unrealistic, no reasons were identified which could be used to discount their use. One possible explanation is that this is the height of the stack above the nearest adjacent building and not above the base of the incinerator. Its inclusion as part of an average value for HEM modeling

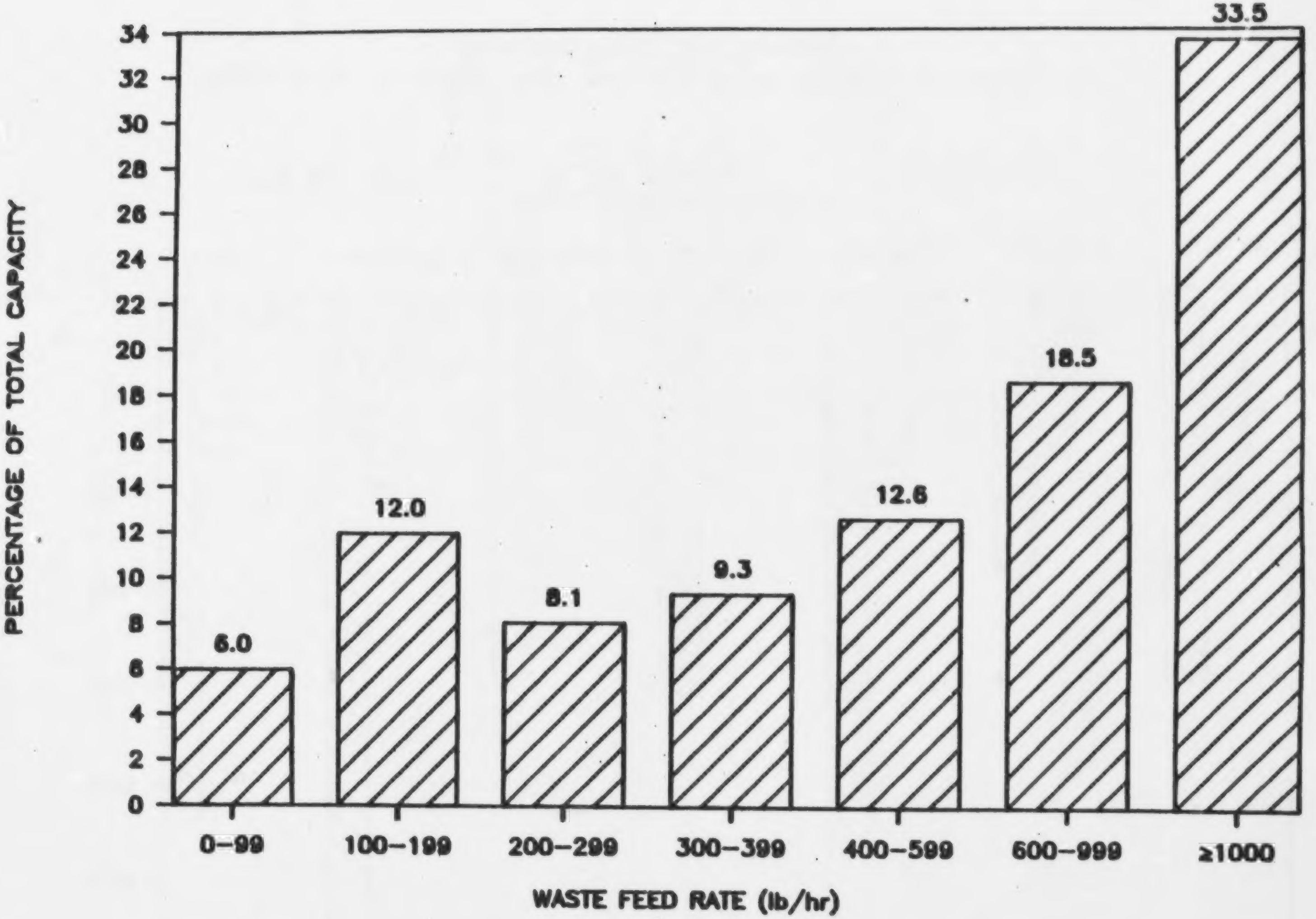

Figure 6-4. Waste Feed Rate Distribution of Incinerators in N.Y. Database by Capacity

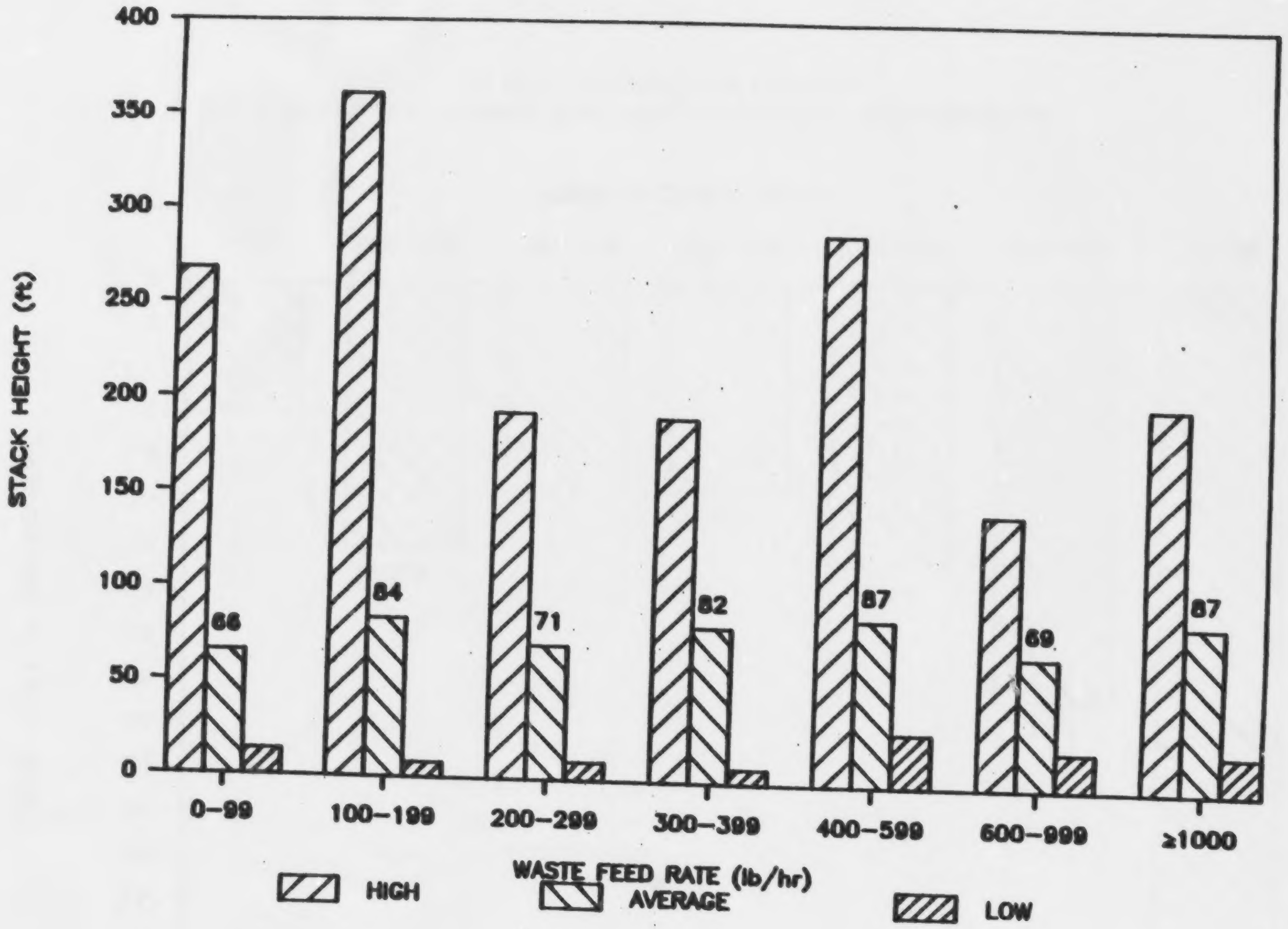

Figure 6-5. Average, High and Low Stack Heights According to Selected Feed Rate Ranges

purposes should have a conservative effect on the stack height estimates. A lower stack height should correspond to higher exposure levels for the population and therefore a conservative estimate of the associated risk.

The results presented in Figure 6-5 show little variation in the average stack height between ranges of unit capacities. In addition, no correlation was found between stack gas temperature (as an indicator of heat recovery equipment) and stack height. The highest of the average stack heights is 87 feet and the lowest is 66 feet. An average stack height of 78 feet would therefore be a representative value for use as the HEM input value, regardless of unit size or heat recovery equipment.

Stack Gas Temperature. The average, high, and low exhaust gas temperature values within a given feed rate range are shown as a function of feed rate ranges in Figure 6-6. As can be seen, the low in all cases is 400°F. Analysis of the NY database indicated several vent streams with exit gas temperatures of less than 400°F. Because it was known that outlet temperatures for units which have heat recovery equipment are limited to approximately 400°F by the stack gas dew point, units with exit gas temperatures which were below 400°F were excluded from analysis. A high value of 2,220°F is shown. Little variation is seen in the average exhaust gas temperatures over the entire range of capacities. For the entire population, the high value of the average temperatures is 1,237°F and the low value is 1,081°F. The average stack gas temperature for the entire database is 1,144°F. This temperature could be used for both the 100 and 1,000 lb/hr model incinerators. Because heat recovery is known to be employed on larger units, an additional 1,000 lb/hr model unit with an exit stack gas temperature of 450°F could be used to show the effects of heat recovery in the modeling. An exit gas temperature of 450°F is appropriate because it provides a comfortable margin above the 400°F acid dew point. This temperature also corresponds to a known unit located at the University of Michigan.[3] If heat recovery equipment is employed, an induced draft fan is often added to overcome the associated pressure drop and maintain design pressures in the combustion chambers.[4] Thus, stack heights should not be affected by the addition of heat recovery equipment.

Stack Gas Exit Velocity. The average, high, and low stack gas exit velocities for a range of feed rates are shown in Figure 6-7. Once again,

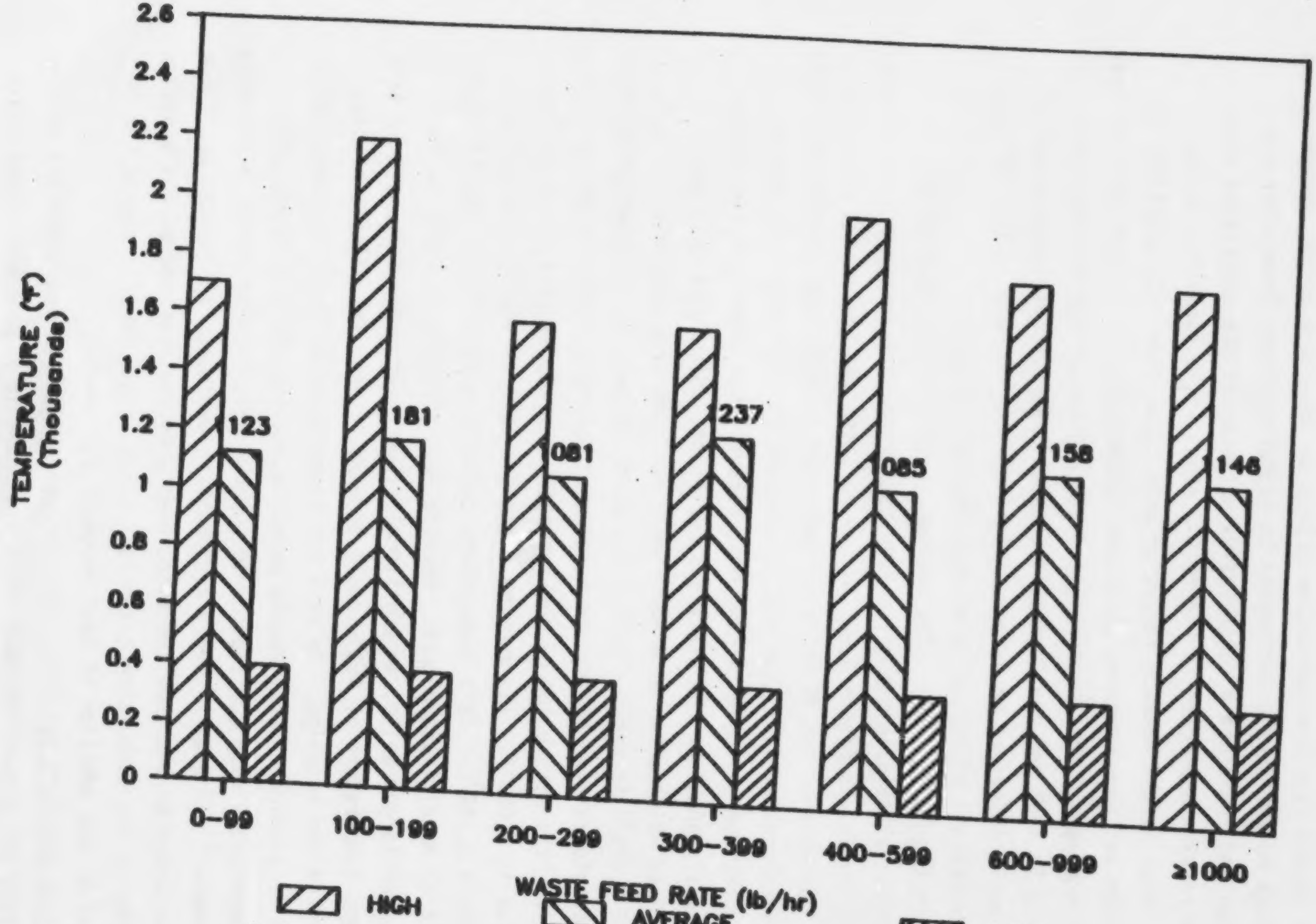

Figure 6-6. Average, High and Low Stack Gas Exit Temperature According to Selected Feed Rate Ranges

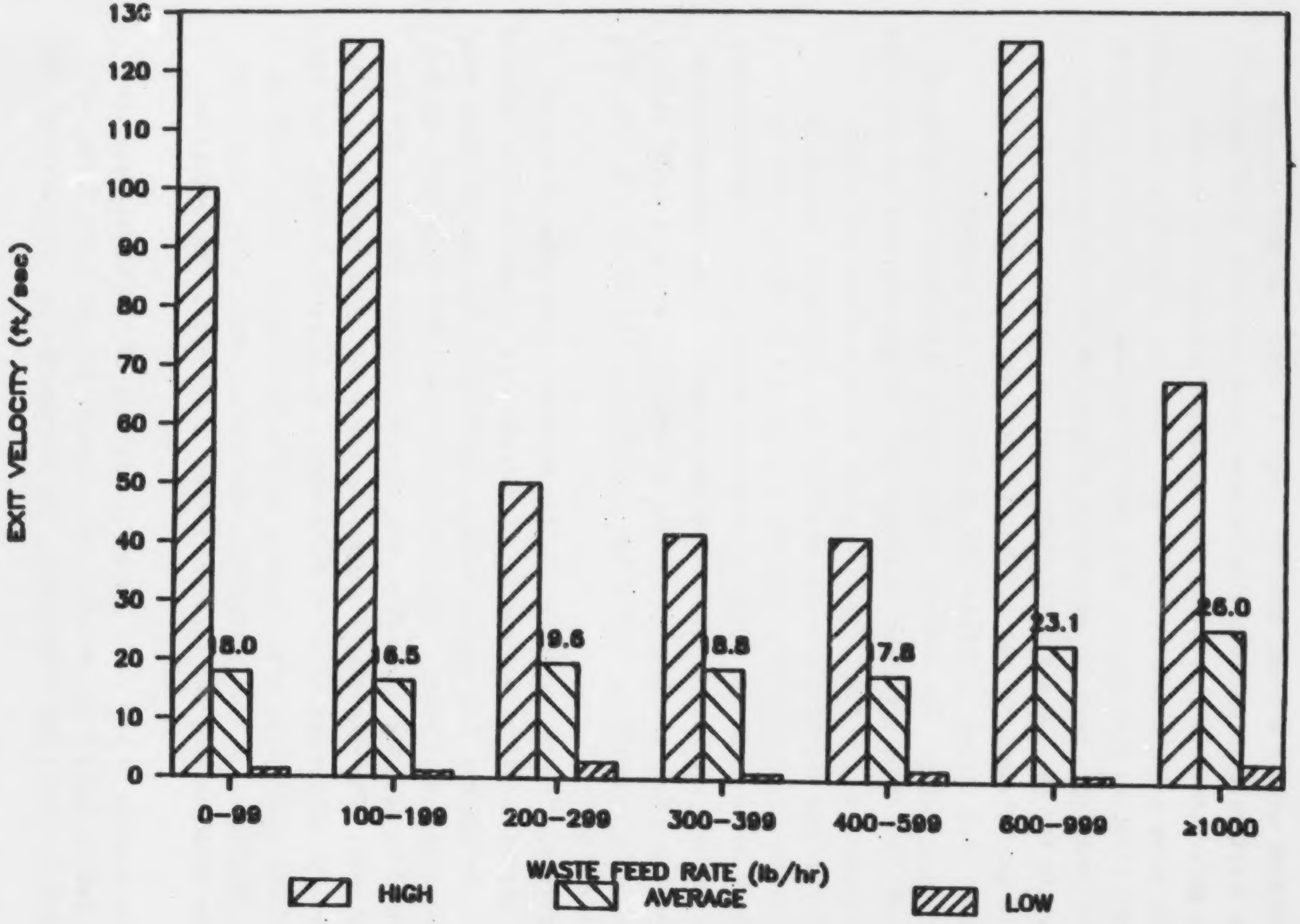

Figure 6-7. Average, High and Low Stack Gas Exit Velocities According to Selected Feed Rate Ranges

the variation within a given capacity range is large. In general, the average stack velocities shown also increase with the capacity of the unit. This is understandable in view of the increasing volumetric flow rate of stack gases with increasing incinerator capacity. Therefore, the average stack gas velocity that applies to a particular model incinerator should be used for modeling. Exit gas velocities of 16.5 and 26.0 ft/sec would be appropriate for the 100 and 1,000 lb/hr model incinerators, respectively. The exit gas velocity for the 1,000 lb/hr heat recovery model should be reduced to 14.8 ft/sec to reflect the reduced exit gas temperature.

Stack Diameter. The average, high, and low stack diameter values for ranges of feed rates are shown in Figure 6-8. As was the case for the other stack parameters, the stack diameters vary within a given size range.

If the same approach used to determine the velocities is used to determine the stack diameters, diameters of 25 and 34 inches would be determined for the 100 and 1,000 lb/hr models, respectively. Unfortunately, these diameters are not realistic when the volumetric flow rate associated with the two models are considered; the volumetric flow for a 1,000 lb/hr unit would be expected to be 10 times greater than the volumetric flow from a 100 lb/hr unit.

Instead, after allowing for the gas velocity differences discussed above, the 25 and 34 inch diameters correspond to a volumetric flow ratio of only 3. To address this inconsistency, the diameter for the 100 lb/hr model was chosen as a base point. The diameter for the 1,000 lb/hr unit was then determined by assuming a gas flow rate 10 times greater than that for the smaller unit. The resultant diameter for the 1,000 lb/hr model unit, after allowing for volume and velocity differences, would be 63 inches. For the case of the 1,000 lb/hr heat recovery model, the diameter was assumed to remain constant. In actual practice, the stack diameters for these units would be determined by the tradeoff between stack draft flow losses and costs.

The results of the stack parameter analysis of the NY database are summarized in Table 6-1. Model incinerators of 100 and 1,000 lb/hr, with two cases for the 1,000 lb/hr model, are recommended as representative for

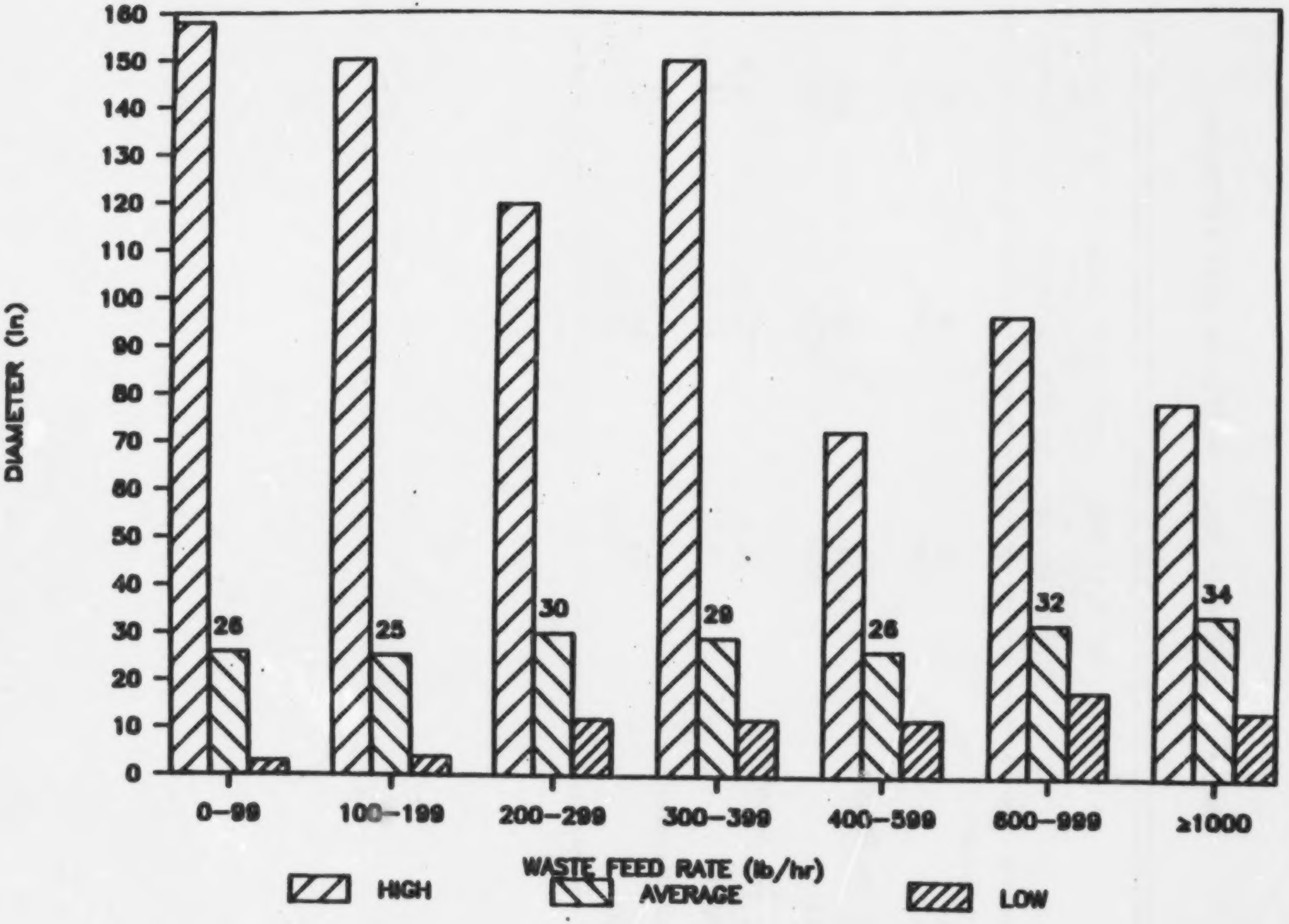

Figure 6-8. Average, High and Low Stack Diameters According to Selected Feed Rate Ranges

TABLE 6-1. SUMMARY OF MODEL INCINERATOR STACK PARAMETERS

	100 lb/hr Model Incinerator with No Heat Recovery	1,000 lb/hr Model Incinerator with No Heat Recovery	1,000 lb/hr Model Incinerator with Heat Recovery
Stack Height			
ft	78	78	78
(m)	(24)	(24)	(24)
Exit Gas Temperature			
°F	1,144	1,144	450
(K)	(891)	(891)	(506)
Exit Gas Velocity			
ft/sec	16.5	26.0	14.8
(m/s)	(5.0)	(7.9)	(4.5)
Stack Diameter			
in	25	66	66
(m)	(0.64)	(1.60)	(1.60)

modeling purposes. The recommended stack height, stack exit gas temperature, and velocity values for each of these models are shown in the table.

6.1.3 Model Incinerator Operating Parameters

The operating parameters required as inputs to the HEM include the annual operating hours and hourly and yearly emissions rates. To determine values for each of these operating parameters, the NY incinerator database was again used to determine the annual operating hours associated with each of the model incinerators. Next the hourly emission rates were determined for each of the models by combining the emissions factor of Section 3.0 with the model capacities previously developed. Finally, the yearly emission rates for each of the models were determined by applying the annual operating hours to the hourly emissions rates.

Annual Operating Hours. The average annual operating hours for a given feed rate range are shown as a function of feed rate ranges in Figure 6-9. As can be seen, the number of annual operating hours increases with increasing unit capacity. Smaller units (less than 200 lb/hr), which operate approximately 1,000 hrs/year, can be characterized as operating five days a week for about 4 hours each day. Larger units (greater than 600 lb/hr), which operate approximately 2,350 hrs/year, can be characterized as operating five days a week for 8 to 10 hrs each day. Therefore, annual operating operating hours of 1,000 and 2,350 may be considered representative for the 100 and 1,000 lb/hr model sizes, respectively.

Hourly Emissions Rates. The emission factors previously developed in Section 3.0 are shown in Table 6-2 along with the corresponding hourly and yearly emissions rates for each of the model incinerators. High and low emissions rates are given for each of the compounds for which data exist. For compounds where only one data point exists, only one rate in shown.

Different particulate matter (PM) emissions rates were used for the two model capacities because, as previously stated, for units of less than 400 lb/hr capacity a larger variation in PM emissions was seen over those of larger units. The high and low emission rates corresponding to this capacity breakpoint are shown. A controlled PM emissions rate is also shown. This rate is based on the baghouse data from the St. Agnes emission test.

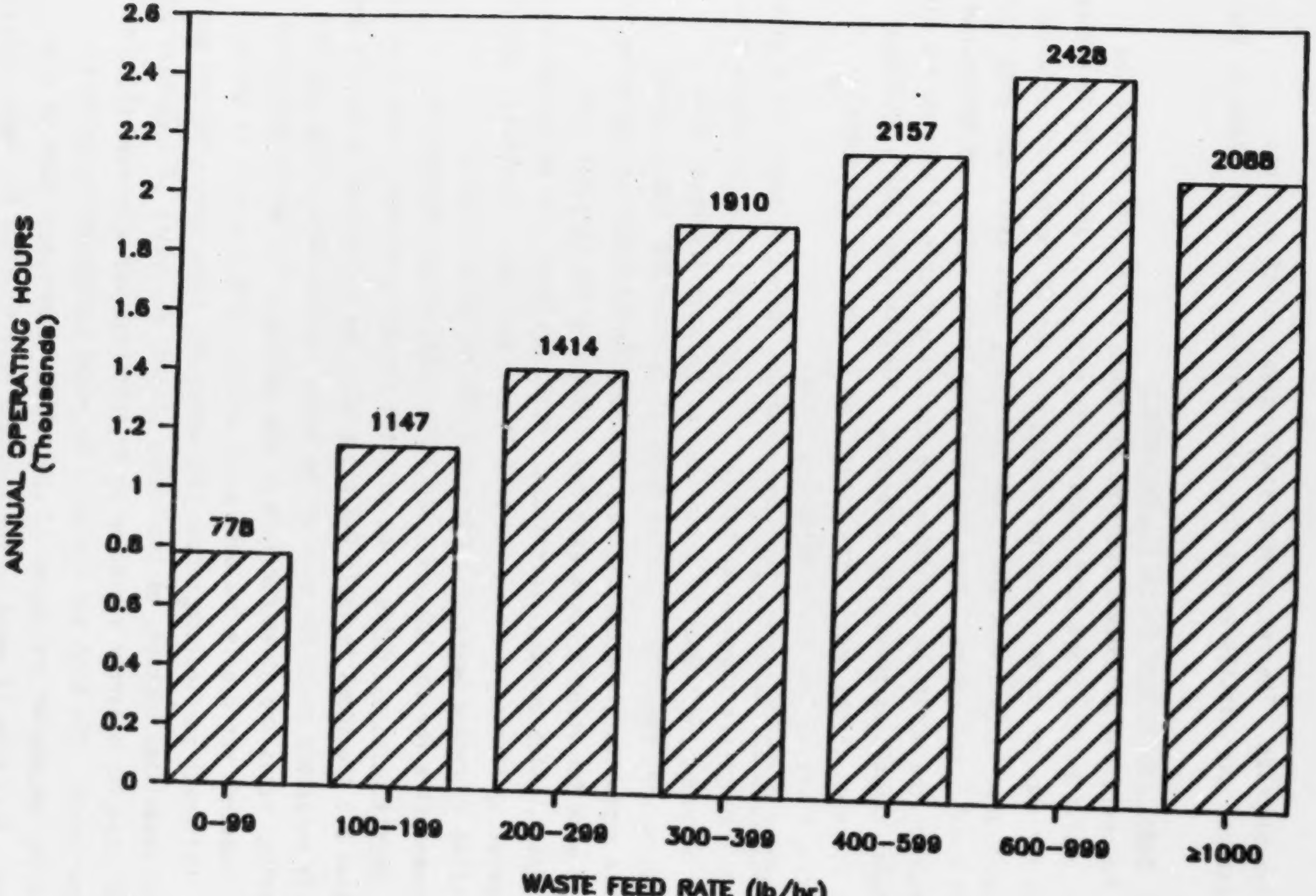

Figure 6-9. Annual Operating Hours According to Selected Feed Rate Changes

TABLE 6-2. SUMMARY OF EMISSIONS FACTORS AND RATES FOR HOSPITAL INCINERATOR MODEL SIZES

Group/Compound	Emissions Factor (kg/Mg feed)	Hourly Emissions Rates (kg)		Yearly Emissions Rates (kg)	
		100 lb/hr Model	1,000 lb/hr Model	100 lb/hr[a] Model	1,000 lb/hr[b] Model
Acid Gases					
Hydrochloric Acid					
High	49.700	2.2564	22.5638	2,256.38	53,024.93
Low	1.450	.0658	.6580	65.80	1,545.59
Sulfur Dioxide					
High	1.505	0.0683	0.6833	68.33	1,605.68
Low	0.735	0.0334	0.3337	33.37	784.17
Nitrogen Oxides					
High	3.910	0.1775	1.7751	177.51	4,171.58
Low	2.320	0.1053	1.0533	105.33	2,475.21
Particulate Matter					
Uncontrolled (100 lb/hr)					
High	13.460	0.6111		611.08	
Low	.285	.0129		12.90	
Uncontrolled (1,000 lb/hr)					
High	18.24		8.2758		19,448.13
Low	0.685		0.3110		730.83
Controlled (all sizes)					
High	1.06	.0481	.4808	48.10	1,129.88
Low	.025	.0011	.0114	1.14	26.67
Trace Metals (Uncontrolled)					
Arsenic					
High	1.46×10^{-4}	6.62×10^{-6}	6.62×10^{-5}	6.6×10^{-3}	1.56×10^{-1}
Low	3.55×10^{-5}	1.61×10^{-6}	1.61×10^{-5}	1.61×10^{-3}	3.79×10^{-2}
Cadmium					
High	3.40×10^{-3}	1.54×10^{-4}	1.54×10^{-3}	1.54×10^{-1}	3.63
Low	7.75×10^{-4}	3.51×10^{-5}	3.51×10^{-4}	3.51×10^{-2}	.824
Chromium					
High	9.75×10^{-4}	4.42×10^{-5}	4.42×10^{-4}	4.42×10^{-2}	1.04
Low	5.10×10^{-5}	2.32×10^{-6}	2.32×10^{-5}	2.32×10^{-3}	5.44×10^{-2}
Iron					
High	9.15×10^{-3}	4.15×10^{-4}	4.15×10^{-3}	4.15×10^{-1}	9.76
Low	1.99×10^{-3}	9.03×10^{-5}	9.03×10^{-4}	9.03×10^{-2}	2.12

TABLE 6-2. SUMMARY OF EMISSIONS FACTORS AND RATES FOR HOSPITAL INCINERATOR MODEL SIZES (CONTINUED)

Group/Compound	Emissions Factor (kg/Mg feed)	Hourly Emissions Rates (kg)		Yearly Emissions Rates (kg)	
		100 lb/hr Model	1,000 lb/hr Model	100 lb/hr[a] Model	1,000 lb/hr[b] Model
Manganese					
High	5.70×10^{-4}	2.59×10^{-5}	2.59×10^{-4}	2.59×10^{-2}	6.08×10^{-1}
Low	7.90×10^{-5}	3.59×10^{-6}	3.59×10^{-5}	3.59×10^{-3}	8.43×10^{-2}
Nickel					
High	2.50×10^{-4}	1.14×10^{-5}	1.14×10^{-4}	1.14×10^{-2}	2.67×10^{-1}
Low	5.40×10^{-5}	2.45×10^{-6}	2.45×10^{-5}	2.45×10^{-3}	5.76×10^{-2}
Lead					
High	2.9×10^{-2}	1.31×10^{-3}	1.31×10^{-2}	1.31	30.8
Low	1.52×10^{-2}	6.90×10^{-4}	6.90×10^{-3}	6.90×10^{-1}	16.2
Dioxins					
(Tetra)TCDD					
High	5.35×10^{-7}	2.43×10^{-8}	2.43×10^{-7}	2.43×10^{-5}	5.71×10^{-4}
Low	2.00×10^{-8}	9.08×10^{-10}	9.08×10^{-9}	9.08×10^{-7}	2.13×10^{-5}
(Penta)PeCDD					
High	3.80×10^{-7}	1.73×10^{-8}	1.73×10^{-7}	1.73×10^{-5}	4.05×10^{-4}
Low	5.50×10^{-8}	2.50×10^{-9}	2.50×10^{-8}	2.50×10^{-6}	5.87×10^{-5}
(Hexa)HxCDD					
High	7.60×10^{-7}	3.45×10^{-8}	3.45×10^{-7}	3.45×10^{-5}	8.11×10^{-4}
Low	1.35×10^{-7}	6.13×10^{-9}	6.13×10^{-8}	6.13×10^{-6}	1.44×10^{-4}
(Hepta)HpCDD					
High	1.92×10^{-6}	8.69×10^{-8}	8.69×10^{-7}	8.69×10^{-5}	2.04×10^{-3}
Low	1.60×10^{-7}	7.26×10^{-9}	7.26×10^{-8}	7.26×10^{-6}	1.71×10^{-4}
(Octa)OCDD					
High	2.74×10^{-6}	1.24×10^{-7}	1.24×10^{-6}	1.24×10^{-4}	2.92×10^{-3}
Low	1.70×10^{-7}	7.72×10^{-9}	7.72×10^{-8}	7.72×10^{-6}	1.81×10^{-4}
Total PCDD					
High	6.26×10^{-6}	2.84×10^{-7}	2.84×10^{-6}	2.84×10^{-4}	6.68×10^{-3}
Low	7.15×10^{-7}	3.25×10^{-8}	3.25×10^{-7}	3.25×10^{-5}	7.63×10^{-4}
Furans					
(Tetra)TCDF					
High	1.04×10^{-6}	4.70×10^{-8}	4.70×10^{-7}	4.70×10^{-5}	1.10×10^{-3}
Low	2.50×10^{-7}	1.14×10^{-8}	1.14×10^{-7}	1.14×10^{-5}	2.67×10^{-4}
(Penta)PeCDF					
High	1.90×10^{-6}	8.60×10^{-8}	8.60×10^{-7}	8.60×10^{-5}	2.02×10^{-3}
Low	4.50×10^{-7}	2.04×10^{-8}	2.04×10^{-7}	2.04×10^{-5}	4.80×10^{-4}

TABLE 6-2. SUMMARY OF EMISSIONS FACTORS AND RATES FOR HOSPITAL INCINERATOR MODEL SIZES (CONTINUED)

Group/Compound	Emissions Factor (kg/Mg feed)	Hourly Emissions Rates (kg) 100 lb/hr Model	Hourly Emissions Rates (kg) 1,000 lb/hr Model	Yearly Emissions Rates (kg) 100 lb/hr[a] Model	Yearly Emissions Rates (kg) 1,000 lb/hr[b] Model
(Hexa)HxCDF					
High	2.82×10^{-6}	1.28×10^{-7}	1.28×10^{-6}	1.28×10^{-4}	3.00×10^{-3}
Low	4.10×10^{-7}	1.86×10^{-8}	1.86×10^{-7}	1.86×10^{-5}	4.37×10^{-4}
(Hepta)HeCDF					
High	3.23×10^{-6}	1.47×10^{-7}	1.47×10^{-6}	1.47×10^{-4}	3.45×10^{-3}
Low	2.75×10^{-7}	1.25×10^{-8}	1.25×10^{-7}	1.25×10^{-5}	2.93×10^{-4}
(Octa)DCDF					
High	2.18×10^{-6}	9.87×10^{-8}	9.87×10^{-7}	9.87×10^{-5}	2.32×10^{-3}
Low	1.05×10^{-7}	4.77×10^{-9}	4.77×10^{-8}	4.77×10^{-6}	1.12×10^{-4}
Total PCDF					
High	1.09×10^{-5}	4.96×10^{-7}	4.96×10^{-6}	4.96×10^{-4}	1.17×10^{-2}
Low	1.63×10^{-6}	7.38×10^{-8}	7.38×10^{-7}	7.38×10^{-5}	1.73×10^{-3}
Low Molecular Organics					
Ethane	0.0015	0.0001	0.0007	0.07	1.60
Ethylene	0.0100	0.0005	0.0045	0.45	10.67
Propane	0.0120	0.0005	0.0054	0.54	12.80
Propylene	0.0110	0.0050	0.0050	0.50	11.74
Trichlorotrifluoroethylene	4.13×10^{-5}	1.87×10^{-6}	1.87×10^{-5}	1.87×10^{-3}	4.40×10^{-2}
Tetrachloromethane	4.96×10^{-5}	2.25×10^{-6}	2.25×10^{-5}	2.25×10^{-3}	5.29×10^{-2}
Trichloroethylene	1.20×10^{-5}	5.43×10^{-7}	5.43×10^{-6}	5.43×10^{-4}	1.27×10^{-2}
Tetrachloroethylene	1.24×10^{-4}	5.65×10^{-6}	5.65×10^{-5}	5.65×10^{-3}	1.33×10^{-1}
Carbon Monoxide					
High	0.85	0.0384	0.3836	38.36	901.53
Low	0.66	0.0300	0.2996	29.26	704.15

[a] Based on 1,000 hours of yearly operation.

[b] Based on 2,350 hours of yearly operation.

6.2 REFERENCES

1. Air Pollution Source Management System, Current Application Data List, Hospital Incinerator List. Compiled by New York State Department of Environmental Conservation, Albany, New York. Transmitted from W. Sountag, New York State Department of Environmental Conservation to T. Moody, Radian Corporation, June 9, 1988.

2. Summary Report, Hospital Statistics, American Hospital Association, 1986 Edition.

3. Doucet, L. G., and Mainka, P. C., Hospital Incinerator Emissions, Risk and Permitting - A case Study. Presented at the 80th Annual Meeting of APCA, New York, New York, June 21-26, 1987.

4. Private communication between E. Aul, Radian Corporation and S. Shuler, Ecolaire Combustion Products, Inc., June 9, 1988.

APPENDIX A

APPENDIX A

STATE REGULATIONS PERTAINING TO INFECTIOUS WASTE MANAGEMENT[1]

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Alabama	1975 Code of Alabama, Section 22-21-20. Alabama State Board of Health Rules and Regulations for Nursing Homes and Hospitals.	All infectious waste generated by nursing homes and hospitals must be incinerated on site.	Bureau of Licensure and Certification State Health Department Room 652 State Office Building Montgomery, Alabama 36130-1701 (205) 261-5105
	No regulations.	Policy is to recommend treatment of infectious waste prior to disposal.	Alabama Department of Environmental Management Land Division 1751 Federal Drive Montgomery, Alabama 36130 (205) 271-7700
Alaska	Laws of Alaska, Title 44, Chapter 46; Title 46, Chapter 3.	All infectious waste generated by medical and veterinary facilities must be incinerated prior to final disposal.	Air and Solid Waste Management Department of Environmental Conservation Pouch O Juneau, Alaska 99811 (907) 465-2666
		The state has statutory authority to regulate infectious waste, but has not yet promulgated regulations.	
Arizona	Arizona Revised Statutes, Title 36, Article 2, General Hospitals. Regulation R9-10-220, Environmental Services, Subsection E.	All infectious waste must be either (1) autoclaved and disposed of in an approved sanitary landfill, or (2) incinerated in an approved incinerator. Variances are given for disposal of untreated waste when there is insufficient treatment capacity.	Bureau of Health Care Institution Licensure Arizona Department of Health Services 1740 West Adams Street Phoenix, Arizona 85007 (602) 255-1115
Arkansas	Act 414 of 1961, as amended by Act 444 of 1965 and Act 454 of 1965. Rules and Regulations for Hospitals and Related Institutions in Arkansas.	All infectious waste generated by hospitals and related institutions must be incinerated or disposed of by other approved methods. Revisions are expected in 1986.	Department of Health Division of Health Facilities Services 4815 W. Markham Street Little Rock, Arkansas 72205-3867 (501) 661-2201

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
	The Solid Waste Management Act (237) of 1971. Arkansas Hazardous Waste Management Act of 1979 (Act 406 of 1979).	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Solid Waste Management Division Department of Pollution control and Ecology P.O. Box 9583 8001 National Drive Little Rock, Arkansas 72219 (501) 562-7444
California	California Health and Safety Code Chapter 6.5, Article 2, Section 25117.5 California Administrative Code, Title 22. Division 4, Chapter 30: Minimum Standards for Management of Hazardous and Extremely Hazardous Waste; Infectious Waste Regulations, effective November 16, 1985.*	Infectious waste must be incinerated, sterilized or treated by other approved methods.	California Department of Health Services Hazardous Materials Management Section 714/744 P Street Sacramento, California 95814 (916) 324-1798
Colorado	Colorado Revised Statutes, 1973, as amended; Title 25, Article 15, Parts 1, 2, and 3: Hazardous Waste Management Act.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Waste Management Division Colorado Department of Health 4210 E. 11th Avenue Denver, Colorado 80220 (303) 320-8333 Ext. 4364
	Chapter 4, Regulations Governing General Hospitals.	Pathological waste must be incinerated. Off-site disposal in approved sites is possible.	Division of Health Facilities Regulations Colorado Department of Health 4210 E. 11th Avenue Denver, Colorado 80220 (303) 320-8333 Ext. 6306
Connecticut	Connecticut General Statutes of 1979, Public Act 79-605. Code 22A-4483 and 22A-115.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Hazardous Waste Management Department of Environmental Protection State Office Building 165 Capitol Avenue Hartford, Connecticut 06106 (203) 566-4869 or 566-5712
Delaware	Delaware Code, Title 7, Chapter 60: Solid Waste Act. Delaware Solid Waste Disposal Regulations, August 1974.	Infectious waste disposal is approved on a case-by-case basis. None has been allowed to go to landfills untreated since the approval process was initiated. Revised regulations have been proposed.	Waste Management Section Department of Natural Resources and Environmental Control 89 King Highway P.O. Box 1401 Dover, Delaware 19903 (302) 736-4781

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
District of Columbia	District of Columbia Hazardous Waste Management Act of 1977, D.C. Law 2-64.	The District has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Department of Consumer and Regulatory Affairs and Environmental Control Division 5010 Overlook Avenue, SW Washington, DC 20032 (202) 767-8414
Florida	Florida Resource Recovery and Management Act (Florida Statutes Annotated, Title 27, Public Health, Chapter 403, Part IV, Enacted by the Laws of 1974, Chapter 342, as amended). Florida Resource Recovery and Management Regulations: Rules of the Department of Environmental Regulation, Chapter 17-7.04.*	Infectious waste must be incinerated or treated by an approved treatment method before being placed in a landfill.	Solid Waste Management Program Department of Environmental Regulation Twin Towers Office Building, 6th Floor 2600 Blair Stone Road Tallahassee, Florida 32301 (904) 488-0300 and Department of Health and Rehabilitative Services 1317 Winewood Boulevard Tallahassee, Florida 32301 (904) 488-2905
Georgia	Code of Georgia, Annotated, Title 43, Chapter 43-16: Solid Waste Management Act of 1972, as amended. Georgia Department of Natural Resources Rules and Regulations for Solid Waste Management, Chapter 391-3-4, 1972, as amended through 1974.	Infectious waste is considered a special waste. Policy is to require incineration or autoclaving before land disposal.	Land Protection Branch Environmental Protection Division Department of Natural Resources Room 724 270 Washington Street, SW Atlanta, Georgia 30334 (404) 656-2833
Hawaii	Hawaii Environmental Laws and Regulations, Vol. I, Title 19, Chapter 342, Part V, as amended by Chapter 230, Laws of 1974. Title II, Department of Health, Chapter 58, Solid Waste Management Control Regulations, November 1981.	All infectious waste must be treated or otherwise rendered safe before disposal. Double bagging is considered a means of rendering an untreated waste safe.	Air and Solid Waste Permit Section Department of Health Amelco Building, 3rd Floor 645 Halekau Wila Street Honolulu, Hawaii 96313
Idaho	Idaho Code, Title 39, Chapter 1. Idaho Solid Waste Management Regulations, Title I, Chapter 6.	All solid waste must be managed to prevent health hazards, public nuisances, and pollution of the environment during treatment, storage and disposal. Policy is to recommend that infectious waste be double bagged prior to disposal.	Hazardous Materials Bureau Department of Health and Welfare State House Boise, Idaho 83720 (208) 334-4107

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Illinois	Illinois Revised Act 101-105, January 1985. State of Illinois Rules and Regulations 35, Subtitle G, Subpart F, Sections 700.601-700.605.	All infectious hospital waste must be rendered innocuous by sterilization or incineration before disposal.	Division of Land Pollution Control Environmental Protection Agency 2200 Churchill Road Springfield, Illinois 62706 (217) 782-6762 or 782-6760
Indiana	Indiana Code, Title 13, Article 7, Environmental Management Act.*	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations. Regulations are being drafted.	Division of Land Pollution Control State Board of Health 1330 West Michigan Street Room A304 Indianapolis, Indiana 46206 (317) 243-9100
	Refuse Disposal Act: Recodified as Indiana Solid Waste Disposal Law IC-36-9-30. Rule 330 IAC 4.	Written approval must be obtained before disposal of infectious waste in a sanitary landfill. A 5-year permit system was established in April, 1987.*	
Iowa	Iowa Code 1985, Section 455B.304. 900--100.3(2) Iowa Administrative Code (IAC)	Land disposal of infectious waste is prohibited unless a special waste authorization is granted that requires autoclaving or formalin treatment before land disposal.	Air and Waste Permit Branch Program Operations Division Iowa Department of Water, Air and Waste Management Henry A. Wallace Building 900 East Grand Street Des Moines, Iowa 50319 (515) 281-8692
Kansas	Kansas Statutes Annotated, Chapter 65, Article 34, as amended. Kansas Administrative Regulations, Title 28. Public Health, Article 29, Regulation 27, Effective May 1984.	Infectious waste must be incinerated, treated before land disposal, or ground to the sewer. Untreated infectious waste may be sent to a hazardous waste land disposal facility or to a sanitary landfill with authorization from the Department.	Solid Waste Management Section Department of Health and Environment Forbes Field, Building 321 Topeka, Kansas 66620 (913) 862-9360, Ext. 309
Kentucky	Kentucky Revised Statutes, 224.005(227)(a).	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Division of Waste Management Cabinet of Natural Resources and Environmental Protection 18 Reilly Road Frankfort, Kentucky 40601 (502) 564-6716

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
	Certificate of Need and Licensure Law, as revised, (originally effective January 1, 1973). 902 Kentucky Administrative Regulations, 20:009, Hospital Facility Regulation.	Hospitals must have an incinerator capable of destroying infectious waste. Hospitals which satisfy the treatment, packaging, and transportation requirements can secure waivers to incinerate the waste in city facilities. Revised regs effective 6/4/85 require that sharp waste (needles, glass, etc.) be separated from other infectious waste. Sharp waste is to be packaged in rigid containers for either incineration or disposal in approved landfills.	Division for Licensing and Regulation Department of Human Resources 275 E. Main Street Frankfort, Kentucky 40601 (502) 564-2800
Louisiana	Louisiana Revised Statutes, Act 449, 30: 1133, Environmental Affairs Act.*	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations. Policy is to allow disposal of treated infectious waste in selected sanitary landfills. Revisions are expected.	Hazardous Waste Division Department of Natural Resources P.O. Box 44066 Baton Rouge, Louisiana 70804 (504) 342-1216
Maine	Title 38 of Main Revised Statutes Annotated.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Bureau of Oil and Hazardous Waste Materials Department of Environmental Protection State House, Station 17 Augusta, Maine 04333 (207) 289-2651
Maryland	Annotated Maryland Code, Health Environment Article, Sections 9-210(g) and 9-229, effective July 1, 1984.	Infectious waste cannot be disposed of in a landfill.	Air Management Administration Department of Health and Mental Hygiene 201 West Preston Street, 2nd Floor Baltimore, Maryland 21201 (301) 225-5260
	Amended Guidelines for the Disposal of Infectious Waste, effective July 1, 1984.	Incineration is the preferred method of treatment.	

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Massachusetts	Massachusetts General Laws, Chapter 111, Subsections 3 and 31-36, and Chapter 111D. 105 CMR 130.354 and 130.355. Hazardous Infectious Waste Disposal Regulations; and 105 CMR 180.275, Regulation for Disposal of Infectious Materials from Independent Laboratories. Massachusetts General Laws, Chapter 21-C.*	Infectious waste must be incinerated or treated before disposal.	Massachusetts Department of Public Health 150 Tremont Street Boston, Massachusetts 02111 (617) 727-2700
	Massachusetts General Laws, Chapter 21-C.*	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Division of Solid and Hazardous Waste 1 Winter Street Boston, Massachusetts 02108 (617) 292-5582
Michigan		As of December 28, 1985, Michigan deleted its list of infectious wastes from the regulations.	Office of Hazardous Waste Management Michigan Department of Natural Resources P.O. Box 30038 Lansing, Michigan 48909 (517) 373-1220
Minnesota	Minnesota Statutes Annotated, Chapters 115A and 116, Enacted by Laws of 1980, as amended. Minnesota Code of Agency Rules, Title 6, Part 4, as amended SW1-12 and SW6-2viii.	Land disposal of infectious waste is prohibited.	Division of Solid and Hazardous Waste Minnesota Pollution Control 1935 West County Road B-2 Roseville, Minnesota 55113 (612) 296-7373
Mississippi	No laws or regulations pertaining to infectious waste management.		Division of Solid/Hazardous Waste Management Bureau of Pollution Control Department of Natural Resources P.O. Box 10385 Jackson, Mississippi 39209 (601) 961-5171
Missouri	Missouri Hospital Licensing Law, Chapter 197 of Missouri Revised Statutes, Rules and Regulations for Hospitals.	Infectious waste generated by hospitals must be either incinerated or autoclaved before being sent to a landfill permitted to accept the waste. Waste is required to be treated on site. The state expects to revise regulations.	Missouri Department of Health Bureau of Hospital Licensing P.O. Box 570 Jefferson City, Missouri 65102 (314) 751-2713

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
	Missouri Hazardous Waste Management Law, Chapter 260 of Revised Statutes of Missouri, 1985, as amended.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Waste Management Program Department of Natural Resources P.O. Box 176 Jefferson City, Missouri 65102 (314) 751-3241
	Missouri Solid Waste Management Law, Chapter 260.200 of Revised Statutes of Missouri, 1975. Missouri Solid Waste Management Rules and Regulations, 10CSR80, Chapters 1-5.	Sterilized infectious waste may be disposed of in any permitted solid waste landfill.	
Montana	Montana Solid Waste Management Act of 1976. Administrative Rules of Montana, Title 16, Chapter 14, Subchapter 5, Solid Waste Management/Refuse Disposal.	Policy is to recommend treatment of infectious waste before land disposal.	Solid and Hazardous Waste Management Bureau Department of Health and Environmental Sciences Cogswell Building, Room B301 Helena, Montana 59620 (406) 444-2821
	Montana Hazardous Waste Act of 1981.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	
Nebraska	Nebraska Environmental Protection Act, Section 81-1501 through 81-1540.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Land Quality Division Department of Environmental Control State House Station P.O. Box 94877 Lincoln, Nebraska 68509 (402) 471-2186
Nevada	Nevada Revised Statutes, Chapter 459, Hazardous Waste Disposal and Solid Waste Disposal. Regulations Governing Solid Waste Management, Effective 1977.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations. Infectious waste generated by hospitals may be placed in a land disposal facility only under approval of the Department.	Division of Environmental Protection Department of Conservation and Natural Resources Capital Complex Carson City, Nevada 89710 (702) 885-4670

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
New Hampshire	New Hampshire Revised Statutes Annotated 151, 1979. Health Facilities Rules and Regulations, effective February 1984. General Requirements for all Facilities, HEF-801.	Infectious waste generated by health care facilities must be incinerated.	Bureau of Health Facilities Administration Division of Public Health Department of Health and Welfare 6 Hazen Drive Concord, New Hampshire 03301 (603) 271-4592
New Jersey	New Jersey Statues Annotated, Title 13: Conservation and Development, Chapter 1E-1. New Jersey Administrative Code, Title 7, Chapter 26, as amended. New regulations dealing with hazardous wastes expected.*	Infectious waste must be rendered noninfectious in accordance with the standards of the New Jersey Department of Health.	Division of Waste Management Department of Environmental Protection 33 East Hanover Street Trenton, New Jersey 08625 (609) 292-9877
	New Jersey Health Care Facilities Planning Act. New Jersey Administrative Code 8:43-B-3.6.*	All infectious waste generated by hospitals must be treated before land disposal. Infectious waste that is not autoclaved or incinerated can be double-bagged for land disposal by a method approved by the Department of Environmental Protection.	New Jersey Department of Health Division of Health Facilities Evaluation CN 370 Trenton, New Jersey 08625 (609) 292-7834
New Mexico	Hazardous Waste Act, Section 74-4-3, as amended through 1981.	No specific regulations on infectious waste. Incineration or sterilization of infectious waste followed by land disposal is recommended.	Solid and Hazardous Waste Management Programs Health and Environment Department P.O. Box 968 Santa Fe, New Mexico 87504-0968 (505) 827-5271 or 827-0020
New York	Environmental Conservation Law, Article 27. Title 6 NCRR part 364. Collection and Transport of Industrial, Commercial, and Certain Other Wastes.*	Anyone transporting a hospital waste off-site (including infectious waste) must have a waste transporter's permit.	Division of Solid and Hazardous Waste Department of Environmental Conservation 50 Wolf Road, Room 417 Albany, New York 12233 (518) 457-3254
	Parts 219 and 222: General Regulation of Refuse and Waste incineration.*	These regulations limit emissions of particulate matter and smoke.	New York State Department of Environmental Conservation 50 Wolf Road Albany, New York 12233 (518) 457-5618

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
	10 NYCRR 405.3(b)(5): Handling of Potentially Infectious Waste.*	The various categories of potentially infectious waste and acceptable methods of disposal for each are presented. All waste must be autoclaved or incinerated prior to disposal.	New York State Department of Health Office of Health Services Management Nelson A. Rockefeller Empire State Plaza Corning Tower, Room 1821 Albany, New York 12237 (518) 474-2121
North Carolina	North Carolina Solid and Hazardous Waste Act, as revised, July 1983. 10 NCAC 10G, Solid Waste Management,. July 1, 1983.	Infectious waste must be treated by an approved method prior to disposal in a landfill.	Solid and Hazardous Waste Management Branch Division of Health Services Department of Human Resources P.O. Box 2091 Raleigh, North Carolina 27602 (919) 733-2178
North Dakota	No governing statute or regulations.	Policy is to require autoclaving or incineration of all infectious waste generated by hospitals and nursing homes. No untreated infectious waste may be disposed of in a landfill. Every hospital and nursing home must have access to a double-chambered, approved incinerator in order to be licensed.	Division of Health Facilities Department of Health State Capitol Building Bismarck, North Dakota 58505 (701) 224-2352
Ohio	Ohio Revised Code, Title 37, Chapter 34, as amended. Ohio Administrative Code, Regulations 3745-27 and 3745-37, effective July 29, 1976.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Division of Solid and Hazardous Waste Management Ohio Environmental Protection Agency 361 East Broad Street Columbus, Ohio 43215 (614) 466-7220
Oklahoma	Oklahoma Statues, Title 63, 1981, Section 1-2001 et seq., Oklahoma Controlled Industrial Waste Disposal Act.*	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations. Current policy is based on CDC guidelines. Infectious waste regulations are being drafted.	Institutional Services, Medical Facilities Department of Health P.O. 53551 1000 N.E. 10th Street, 4th Floor Oklahoma City, Oklahoma 73152 (405) 271-6811
Oregon	Oregon Revised Statutes, Chapter 459, as amended. Oregon Administrative Rules, Chapter 340, Division 61.	Land disposal of infectious waste is controlled through the permitting process for land disposal facilities.	Hazardous and Solid Waste Division Department of Environmental Quality P.O. Box 1760 Portland, Oregon 97207 (503) 229-6266

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Pennsylvania	Pennsylvania Statutes, 62 PS 901-1059, Public Welfare Code. Pennsylvania Code, Title 28, Chapter 147.74, Pennsylvania State Health Department Regulations: Disposal of Bacterial and Pathological Wastes that are Generated in Hospitals and Medical Care Facilities.*	Current policy is to allow off-site sterilization of infectious waste. New regulations are being drafted.	Bureau of Waste Management Department of Environmental Resources Fulton Building, 8th Floor P.O. Box 2063 Harrisburg, Pennsylvania 17120 (717) 787-6239
	25 Pa. Code 127.12(a)(5)*	Best Available Technology requirements for hospital/infectious waste incinerator facilities include stack emission limitations, ambient impact analyses, operating, testing and monitoring requirements. These regulations are in draft review, effective June 9, 1987.	Bureau of Air Quality Control Department of Environmental Resources Fulton Building, 18th Floor P.O. Box 2063 Harrisburg, Pennsylvania 17120 (717) 787-4324
Rhode Island	Rhode Island Hazardous Waste Management Act of 1978. Hazardous Waste Rules and Regulations for Hazardous Waste Generation, Transportation, Treatment, Storage and Disposal - Effective July 18, 1984.	Infectious waste is regulated as a hazardous waste.	Division of Air Hazardous Materials Department of Environmental Management 204 Cannon Building 75 Davis Street Providence, Rhode Island 02908 (401) 277-2797
South Carolina	Code of Laws of South Carolina, 1976, Sections 44-56-10 through 44-56-140, Hazardous Wastes.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations. The state recommends that infectious hospital waste be incinerated or otherwise treated before land disposal.	Bureau of Solid and Hazardous Waste South Carolina Department of Health and Environmental Control 2600 Bull Street Columbia, South Carolina 29201 (803) 758-5681
South Dakota	South Dakota Codified Laws, Chapter 34A-6-2, Solid Waste Disposal Act.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Office of Air Quality and Solid Waste Department of Water and Natural Resources Joe Foss Building 523 East Capitol Avenue Pierre, South Dakota 57501 (605) 773-3153

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Tennessee	Tennessee Hazardous Waste Management Act of 1977, as amended. Tennessee Solid Waste Disposal Act, as amended.*	The state is initiating rulemaking action.	Division of Solid Waste Management Tennessee Department of Public Health and Environment Customs House, 4th Floor 601 Broadway Street Nashville, Tennessee 37219-5403 (615) 741-3424
	Tennessee Code Annotated, 6811-201 through 217 Minimum Standards and Regulations for Hospitals, 1974.*	All infectious waste generated by hospitals must be incinerated in closed incinerators on elevated platforms.	Hospital Licensing Board 283 Plus Park Nashville, Tennessee 37210 (615) 367-6200
Texas	Revised Civil Statutes of the State of Texas Annotated, Article 4477-7 Texas Solid Waste Disposal Act; and Article 4477-1, Texas Sanitation and Health Protection Law, as amended. Texas Administrative Code 325.136(b)(1), Texas Department of Health, Municipal Solid Waste Management Regulations, effective July 1983, as amended.*	Infectious waste is regulated as a special waste. Incineration is the preferred method of treatment. Untreated waste may be double bagged and disposed of in a Type I municipal landfill.	Bureau of Solid Waste Management Texas Department of Health 1100 West 49th Street, T601A Austin, Texas 78756 - 3199 (512) 458-7271
Utah	Utah Code Annotated, Title 26, Chapter 14, Utah Solid and Hazardous Waste Act, Effective June, 1981.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Bureau of Solid and Hazardous Waste Department of Health P.O. Box 45500 Salt Lake City, Utah 84145-0501 (801) 533-4145
Vermont	Vermont Statutes Annotated, Title 10, Chapter 159. Hazardous Waste Management Regulations, as amended September 13, 1984, Section 6602(2)(a)(14).	Infectious waste is regulated as a hazardous waste.	Hazardous and Solid Waste Management Division Department of Water Resources and Environmental Engineering Agency of Environmental Conservation State Office Building Montpelier, Vermont 05602 (802) 828-3395
Virginia	Code of Virginia, Title 32.1, Chapter 6, Article 3. Virginia Regulations Governing Disposal of Solid Waste, April, 1971.	Infectious wastes are not as regulated as hazardous wastes. Waste generators must have special permission to dispose of nonmunicipal waste. Rules do not preclude land disposal of untreated infectious waste.	Division of Solid and Hazardous Waste Management Department of Health Monroe Building, 11th Floor 101 North 14th Street Richmond, Virginia 23219 (804) 225-2667

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Washington	Revised Code of Washington, Hazardous Waste Disposal Chapter 70.105.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Hazardous Waste Section Department of Ecology Mail Stop PV-11 Olympia, Washington 98504-8711 (206) 459-6322
	Revised Code of Washington, Hospital Licensing and Regulation Statute, Chapter 70.41. Washington Administrative Code, 248-180-170, Hospital Rules and Regulations.	Infectious waste generated by hospitals must be incinerated or disposed of by other approved methods. Approved methods include autoclaving, retorting, or double bagging before land disposal.	Department of Social and Health Services Facility Licensing Certification Section of the Health Services Division Mail Stop ET-31 Olympia, Washington (206) 753-7039
West Virginia	Code of West Virginia, Chapter 20, Article 5E, Effective July 7, 1981.*	Infectious waste must be autoclaved and/or incinerated before land disposal. Infectious waste regulations are being revised.	State Health Department 1800 Washington Street, East Charleston, West Virginia 25305 (304) 348-2970
Wisconsin	Wisconsin Statutes Annotated, Chapter 144, as amended.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Bureau of Solid Waste Management Department of Natural Resources P.O. Box 7921 Madison, Wisconsin 53707 (608) 266-2111
	Chapter NR 181, and guidance summary "Handling and Disposal of Pathological Waste."	Policy is to recommended incineration of infectious waste. Infectious waste which as been autoclaved or sterilized may be bagged and disposed of in an engineered landfill.	
Wyoming	No regulations pertaining to infectious waste management.		Solid Waste Management Program State of Wyoming Department of Environmental Quality Herschler Building 122 West 25th Street Cheyenne, Wyoming 82002 (307) 777-7752
			Department of Health and Social Services Division of Health and Medical Services 4th Floor Hathaway Building Cheyenne, Wyoming 82002 (307) 777-7121

*Denotes regulations as of June, 1987.

APPENDIX B

APPENDIX B - ADDITIONAL HOSPITAL WASTE INCINERATOR EMISSIONS DATA

The Monitoring and Laboratory Division of the California Air Resources Board conducted evaluation tests on the refuse incinerator at the Stanford University Environmental Safety Facility, Stanford, California, and a retest on a hosital refuse incinerator at the Sutter General Hospital, Sacramento, California. The results of these tests are presented in two reports titled "Evaluation Retest on a Hospital Refuse Incinerator at Sutter General Hospital, Sacramento, CA." April 1988 (ARB/ML-88-026) and "Evaluation Test on a Refuse Incinerator at Stanford University Environmental Safety Facility," Stanford, CA., August 1988 (ARB/ML-88-025). To provide these test results, EPA has extracted tables of emissions data for particulate matter, hydrogen chloride, chlorinated dibenzo-p-dioxins and dibenzofurans and other compounds from these reports and incorporated them into Appendix B.

Test Data for the Hospital Refuse Incinerator at Sutter General Hospital, Sacramento, CA., California Air Resources Board Test Report, ARB/ML-88-026, April 1988.

The staff of the California Air Resources Board tested and, after design modifications were made, retested the dual chamber, Thermtec - Model/No. 67-SA, hospital refuse incinerator at the Sutter General Hospital, Sacramento, CA. The hospital has a heat recovery system, Model HR-1000-2-SK-9 manufactured by Thermtec, to recover heat from the exhaust gases. The initial tests were conducted from April 28 through May 1, 1987. The system was modified to reduce the amount of dilution air entering the exhaust gas system. The system was then retested during the period from July 29 through August 3, 1987. The results of these tests are presented in the following tables:

TABLE 1

Average Refuse Feed Rate to the Incinerator During the Test Period

DATE	TIME	NUMBER OF [a] INFECTIOUS BOXES (pounds)	NUMBER OF [b] CARTS (pounds)	PROCESS WEIGHT RATE, LB/HR
7-29-87	1300-1800	13 (264)	36 (2700)	593
7-30-87	0900-1400	14 (284)	29 (2175)	492
7-31-87	0900-1900[c]	37 (751)	49 (3675)	443
8-3-87	1300-2300	34 (690)	40 (3000)	369

[a] Infectious boxes weigh 20.3 pounds each

[b] Typical cart trash weight is 75 pounds

[c] On July 31, 1987 the refuse loading ram to the bottom chamber was inoperative from approximately 1000 to 1500 HOURS. During this period the bottom chamber was in a burndown configuration with an increased natural gas comsumption in the upper chamber to satisfy boiler heating requirements.

TABLE B-2

DAILY AVERAGE STACK CONDITIONS FOR INCINERATOR AT SUTTER GENERAL HOSPITAL

Date	Stack Gas Velocity (Ft/Sec)	Stack Gas Flow Rate (DSCFH)	Moisture Content, (% By Volume)	Stack Gas Temperature (°F)
7-29-87	10.9	2687	13.2	328
7-30-87	13.4	3145	13.2	369
7-31-87	13.0	2833	15.5	409
8-3-87	11.9	2894	10.9	357

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TABLE B-3

DAILY AVERAGE CONCENTRATIONS OF SELECTED GASEOUS AIR POLLUTANTS FROM THE SUTTER GENERAL INCINERATOR

DATE	PM d/	O2 a/	CO2 a/	CO a/	NOX b/	SO2 b/	HC bc/	THC c/
	GR/DSCF	PERCENT	PERCENT	PPMV	PPMV	PPMV	PPMV	PPMV
7-29-87	-	15.6	4.0	<50	130	50	<2	-
7-30-87	-	12.1	5.5	<50	90	13	<2	215
7-31-87	0.024 f/	12.5	5.2	<50	80	11 e/	<2	224 g/
8-3-87	0.050 h/	13.9	4.8	<50	100	22	12	-

a/ THE O2, CO2 AND CO VALUES WERE USED TO DETERMINE THE MOLECULAR WEIGHT OF THE STACK GAS.

b/ NOX, SO2 AND HC VALUES ARE CORRECTED TO 3 PERCENT O2.

c/ TOTAL HYDROCARBON DATA REPORTED AS PROPANE.

d/ REPORTED AT ACTUAL FLUE GAS O2 CONCENTRATIONS.

e/ SO2 ANALYZER INOPERATIVE DURING PART OF TEST PERIOD.

f/ AVERAGE OF FOUR TEST RUNS (0.027 , 0.021 , 0.023 AND 0.024 GR/DSCF)

g/ AVERAGE OF TWO TEST RUNS (289 AND 159 PPMV)

h/ AVERAGE OF TWO TEST RUNS (0.043 AND 0.057 GR/DSCF)

SYMBOL (<) INDICATES BELOW DETECTABLE LIMIT.

TABLE B-4

DAILY AVERAGE CONCENTRATIONS OF OXYGEN,CARBON DIOXIDE, CARBON MONOXIDE,OXIDES OF NITROGEN,SULFUR DIOXIDE, TOTAL HYDROCARBONS,PARTICULATE MATTER AND HYDROCHLORIC ACID IN THE STACK GAS AT SUTTER GENERAL HOSPITAL, SACRAMENTO,CA

DATE	PM GR/DSCF	O2 a/ PERCENT	CO2 a/ PERCENT	CO a/ PPMV	NOX b/ PPMV	SO2 b/ PPMV	HC bc/ PPMV	HCL b/ PPMV
4-28-87	0.023	19.4	1.2	<50	70	20	<1	860
4-29-87	0.023	19.4	1.3	<50	70	30	<1	2500
5-1-87	0.012	19.3	1.1	<50	60	6	<1	2130

a/ THE O2,CO2 AND CO VALUES WERE USE TO DETERMINE THE MOLECULAR WEIGHT OF THE STACK GAS.

b/ NOX,SO2,HC AND HCL DATA CORRECTED TO 3 PERCENT O2.

c/ TOTAL HYDROCARBON DATA REPORTED AS PROPANE.

SYMBOL (<) INDICATES BELOW DETECTABLE LIMIT.

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TABLE B-5

PARTICULATE MATTER AND HYDROCHLORIC ACID CONCENTRATIONS AND MASS EMISSION RATES

DATE RUN	NO.	PM GR/DSCF	PM LB/HR	HCl PPM	HCl LB/HR
7-30-87	HCl-1S	-	-	315	5.79
7-31-87	HCl-2S	-	-	282	4.46
	HCl-3S	-	-	159	2.59
	M5-1S	0.027	0.74	-	-
	M5-2S	0.021	0.50	-	-
	M5-3S	0.023	0.55	-	-
	M5-4S	0.024	0.53	-	-
8-3-87	M5-5S	0.043	1.09	-	-
	M5-6S	0.057	1.38	-	-

Date	PM GR/DSCF	PM LB/HR	HCL PPM	HCL LB/HR
4-28-87	0.023	0.94	72	1.98
4-29-87	0.023	1.05	210	6.54
5-1-87	0.012	0.49	191	5.21

TABLE B-6

PCDD/PCDF MASS EMISSION RATES
(ng/sec)

RUN #	DT-1S	DT-2S	DT-3S	DT-4S
DIOXINS				
2,3,7,8-TCDD	<0.042	<0.039	0.058	<0.035
Total TCDD	<0.394	<0.058	3.958	<0.033
1,2,3,7,8-PeCDD	<0.167	<0.111	0.241	<0.159
Total PeCDD	<0.256	0.544	6.830	<0.095
1,2,3,4,7,8-HxCDD	<0.394	<0.212	0.252	<0.089
1,2,3,6,7,8-HxCDD	<0.361	<0.226	0.427	<0.089
1,2,3,7,8,9-HxCDD	<0.328	<0.162	<0.213	<0.089
Total HxCDD	0.788	1.452	10.63	0.542
1,2,3,4,6,7,8-HpCDD	3.778	0.949	9.003	0.620
Total HpCDD	6.932	2.011	18.55	1.239
Total OCDD	7.294	2.793	19.60	2.556
Total PCDD	15.66	6.860	59.57	4.466
FURANS				
2,3,7,8-TCDF	0.072	0.131	0.760	<0.092
Total TCDF	<0.328	3.910	45.94	2.459
1,2,3,7,8-PeCDF	0.124	0.586	3.244	0.356
2,3,4,7,8-PeCDF	<0.147	0.357	2.200	0.224
Total PeCDF	<1.839	5.558	40.84	5.151
1,2,3,4,7,8-HxCDF	0.328	0.687	2.755	<0.309
1,2,3,6,7,8-HxCDF	<0.325	0.391	2.871	<0.580
1,2,3,7,8,9-HxCDF	<0.689	0.148	0.970	<0.383
2,3,4,6,7,8-HxCDF	<1.084	0.139	2.957	<0.735
Total HxCDF	<3.548	6.675	42.96	5.500
1,2,3,4,6,7,8-HpCDF	2.858	2.905	28.29	2.420
1,2,3,4,7,8,9-HpCDF	0.108	0.614	5.906	0.519
Total HpCDF	2.858	5.865	52.51	5.151
Total OCDF	0.591	6.089	68.65	8.017
Total PCDF	9.166	28.10	250.9	26.28

NOTES
< Indicates below limit of detection (MDL)
* Chemical interference
** MPC (Maximum possible concentration)
- Total includes MDLs for homologues below the detection limit

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TABLE B-7

PCDD/PCDF CONCENTRATIONS IN STACK GAS
(ng/dscm corrected to 12% CO_2)

RUN #	DT-1S	DT-2S	DT-3S	DT-4S
DIOXINS				
2,3,7,8-TCDD	<0.188	<0.140	0.280	<0.168
Total TCDD	<1.732	<0.210	19.07	<0.157
1,2,3,7,8-PeCDD	<0.736	<0.400	1.159	<0.765
Total PeCDD	<1.126	1.949	32.90	<0.457
1,2,3,4,7,8-HxCDD	<1.732	<0.759	1.215	<0.429
1,2,3,6,7,8-HxCDD	<1.587	<0.809	2.056	<0.429
1,2,3,7,8,9-HxCDD	<1.443	<0.580	<1.028	<0.429
Total HxCDD	3.464	5.196	51.22	2.612
1,2,3,4,6,7,8-HpCDD	16.60	3.398	43.37	2.985
Total HpCDD	30.45	7.195	89.35	5.970
Total OCDD	32.04	9.993	94.40	12.31
Total PCDD	68.81	24.54	286.9	21.51
FURANS				
2,3,7,8-TCDF	<0.317	0.470	3.664	<0.448
Total TCDF	1.443	13.99	221.3	11.85
1,2,3,7,8-PeCDF	<0.548	2.099	15.6	1.716
2,3,4,7,8-PeCDF	<0.649	1.279	10.6	1.082
Total PeCDF	8.08	19.89	196.8	24.81
1,2,3,4,7,8-HxCDF	<1.443	2.458	13.3	<1.492
1,2,3,6,7,8-HxCDF	<1.429	1.399	13.8	<2.798
1,2,3,7,8,9-HxCDF	<3.031	0.530	4.673	<1.847
2,3,4,6,7,8-HxCDF	<4.762	0.500	14.2	<3.545
Total HxCDF	15.59	23.88	206.9	26.49
1,2,3,4,6,7,8-HpCDF	12.56	10.39	136.3	11.66
1,2,3,4,7,8,9-HpCDF	<0.476	2.199	28.4	2.500
Total HpCDF	12.56	20.99	252.9	24.81
Total OCDF	2.60	21.79	330.7	38.62
Total PCDF	40.3	100.5	1209	126.6

NOTES
< indicates below limit of detection (MDL)
* Chemical interference
** MPC (Maximum possible concentration)
- Total includes MDLs for homologues below the detection limit

TABLE B-8

PCDD/PCDF CONCENTRATIONS IN STACK GAS
(ng/dscm)

RUN #	DT-1S	DT-2S	DT-3S	DT-4S
DIOXINS				
2,3,7,8-TCDD	<0.019	<0.015	0.026	<0.015
Total TCDD	<0.173	<0.023	1.748	<0.014
1,2,3,7,8-PeCDD	<0.074	<0.043	0.106	<0.070
Total PeCDD	<0.113	0.211	3.016	<0.042
1,2,3,4,7,8-HxCDD	<0.173	<0.082	0.111	<0.039
1,2,3,6,7,8-HxCDD	<0.159	<0.088	0.188	<0.039
1,2,3,7,8,9-HxCDD	<0.144	<0.063	<0.094	<0.039
Total HxCDD	0.346	0.563	4.695	0.239
1,2,3,4,6,7,8-HpCDD	1.660	0.368	3.975	0.274
Total HpCDD	3.045	0.779	8.19	0.547
Total OCDD	3.20	1.083	8.65	1.129
Total PCDD	6.88	2.659	26.30	1.97
FURANS				
2,3,7,8-TCDF	<0.031	0.050	0.335	<0.041
Total TCDF	0.144	1.515	20.28	1.085
1,2,3,7,8-PeCDF	<0.054	0.227	1.432	0.157
2,3,4,7,8-PeCDF	<0.064	0.138	0.971	0.099
Total PeCDF	0.808	2.154	18.03	2.274
1,2,3,4,7,8-HxCDF	<0.144	0.266	1.216	<0.136
1,2,3,6,7,8-HxCDF	<0.142	0.151	1.267	<0.256
1,2,3,7,8,9-HxCDF	<0.303	0.057	0.428	<0.169
2,3,4,6,7,8-HxCDF	<0.476	0.054	1.305	<0.324
Total HxCDF	1.558	2.587	18.96	2.428
1,2,3,4,6,7,8-HpCDF	1.255	1.125	12.49	1.068
1,2,3,4,7,8,9-HpCDF	<0.047	0.238	2.607	0.229
Total HpCDF	1.255	2.273	23.18	2.274
Total OCDF	0.259	2.360	30.31	3.539
Total PCDF	4.026	10.89	110.7	11.60

NOTES
< Indicates below limit of detection (MDL)
* Chemical interference
** MPC (Maximum possible concentration)
- Total includes MDLs for homologues below the detection limit

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TABLE B-9

PCDD/PCDF MASS EMISSION RATES IN STACK GAS
(ng/sec)

RUN # Sampling date	DT-1S 7-29-87	DT-2S 7-30-87	DT-3S 7-30-87
DIOXINS			
2,3,7,8-TCDD	0.24	< 0.11	0.140
Total TCDD	25.4	21.0	33.3
1,2,3,7,8-PeCDD	4.03	2.39	3.8
Total PeCDD	138	103	106
1,2,3,4,7,8-HxCDD	10.9	8.96	10.1
1,2,3,6,7,8-HxCDD	21.5	18.7	21.5
1,2,3,7,8,9-HxCDD	13.4	10.5	12.5
Total HxCDD	291	236	242
1,2,3,4,6,7,8-HpCDD	157	13.8	169
Total HpCDD	349	334	355
Total OCDD	237	265	269
Total PCDD	1041	959 **	1005
FURANS			
2,3,7,8-TCDF	6.51	4.86	6.05
Total TCDF	329	253	256
1,2,3,7,8-PeCDF	30.0	25.2	30.6
2,3,4,7,8-PeCDF	36.4	29.7	37.0
Total PeCDF	407	342	333
1,2,3,4,7,8-HxCDF	50.0	43.6	49.6
1,2,3,6,7,8-HxCDF	53.2	41.1	43.8
1,2,3,7,8,9-HxCDF	14.5	13.9	17.5
2,3,4,6,7,8-HxCDF	115	104	103
Total HxCDF	463	374	431
1,2,3,4,6,7,8-HpCDF	233	244	236
1,2,3,4,7,8,9-HpCDF	45.5	51.1	56.2
Total HpCDF	437	462	477
Total OCDF	381	404	396
Total PCDF	2016	1834	1893

NOTES
< indicates below limit of detection (MDL)
** - Total includes MDLs for homologues below the detection limit

TABLE B-10

PCDD/PCDF CONCENTRATIONS IN STACK GAS
(corrected to 12 percent CO2)

RUN # Sampling date	DT-1S 7-29-87	DT-2S 7-30-87	DT-3S 7-30-87
	(ng/dscm)	(ng/dscm)	(ng/dscm)
DIOXINS			
2,3,7,8-TCDD	0.56	< 0.22	0.29
Total TCDD	60.0	43.2	68.1
1,2,3,7,8-PeCDD	9.53	4.91	7.83
Total PeCDD	327	212	218
1,2,3,4,7,8-HxCDD	25.9	18.4	20.6
1,2,3,6,7,8-HxCDD	50.9	38.5	44.1
1,2,3,7,8,9-HxCDD	31.8	21.5	25.7
Total HxCDD	688	486	495
1,2,3,4,6,7,8-HpCDD	372	28	347
Total HpCDD	827	686	727
Total OCDD	560	545	551
Total PCDD	2462	1972 **	2059
FURANS			
2,3,7,8-TCDF	15.39	9.05	12.38
Total TCDF	779	520	525
1,2,3,7,8-PeCDF	71.0	51.8	62.7
2,3,4,7,8-PeCDF	86.2	61.1	75.8
Total PeCDF	962	702	681
1,2,3,4,7,8-HxCDF	118.2	89.6	101.6
1,2,3,6,7,8-HxCDF	125.8	84.4	89.7
1,2,3,7,8,9-HxCDF	34.3	28.6	35.8
2,3,4,6,7,8-HxCDF	273	213	211
Total HxCDF	1095	766	883
1,2,3,4,6,7,8-HpCDF	552	502	483
1,2,3,4,7,8,9-HpCDF	107.7	105.1	115.2
Total HpCDF	1033	950	976
Total OCDF	900	830	812
Total PCDF	4770	3770	3877

NOTES
dscm - dry standard cubic meter at 68 F and one atmosphere
< indicates below limit of detection (MDL)
** - Total includes MDLs for homologues below the detection limit

TABLE B-11

PCDD/PCDF CONCENTRATIONS IN STACK GAS

(ng/dscm)

RUN # Sampling date	DT-1S 7-29-87	DT-2S 7-30-87	DT-3S 7-30-87
DIOXINS			
2,3,7,8-TCDD	0.19	< 0.07	0.10
Total TCDD	20.0	14.4	22.7
1,2,3,7,8-PeCDD	3.18	1.64	2.61
Total PeCDD	109	70.5	72.6
1,2,3,4,7,8-HxCDD	8.63	6.14	6.86
1,2,3,6,7,8-HxCDD	17.0	12.8	14.7
1,2,3,7,8,9-HxCDD	10.6	7.17	8.57
Total HxCDD	229	162	165
1,2,3,4,6,7,8-HpCDD	124	9.48	116
Total HpCDD	276	229	242
Total OCDD	187	182	184
Total PCDD	821	657 **	686
FURANS			
2,3,7,8-TCDF	5.13	3.02	4.13
Total TCDF	260	173	175
1,2,3,7,8-PeCDF	23.7	17.3	20.9
2,3,4,7,8-PeCDF	28.7	20.4	25.3
Total PeCDF	321	234	227
1,2,3,4,7,8-HxCDF	39.4	29.9	33.9
1,2,3,6,7,8-HxCDF	41.9	28.1	23.9
1,2,3,7,8,9-HxCDF	11.4	9.55	11.9
2,3,4,6,7,8-HxCDF	91.1	71.0	70.2
Total HxCDF	365	256	294
1,2,3,4,6,7,8-HpCDF	184	167	161
1,2,3,4,7,8,9-HpCDF	33.9	35.0	33.4
Total HpCDF	344	317	325
Total OCDF	300	277	271
Total PCDF	1590	1257	1292

NOTES

dscm - dry standard cubic meter at 68 F and one atmosphere

< indicates below limit of detection (MDL)

** - Total includes MDLs for homologues below the detection limit

TABLE B-12

MASS EMISSION RATES OF TRACE METALS IN STACK GAS

MASS EMISSION RATES, POUNDS/HOUR[a/]

RUN NO.	As.	Cd	Cr	Fe	Mn	Ni	Pb
M5-1S	0.45E-5	5.90E-4	9.84E-5	2.99E-3	1.14E-4	< 6.71E-5	7.65E-3
M5-2S	ND	1.86E-4	4.22E-5	3.12E-3	2.55E-5	< 6.09E-5	2.01E-3
M5-3S	ND	1.95E-4	5.20E-5	0.37E-3	1.67E-5	< 6.96E-5	2.97E-3
M5-4S	ND	2.07E-4	< 4.87E-5	0.70E-3	0.31E-4	< 7.30E-5	2.34E-3
M5-5S	ND	6.68E-4	7.30E-5	1.52E-3	0.80E-4	< 9.13E-5	6.31E-3
M5-6S	0.11E-5	6.85E-4	1.16E-4	1.06E-2	2.55E-4	< 7.94E-5	1.23E-2

[a/] Symbol (<) indicates below limit of detection.

ND Not Determined

TABLE B-13

CONCENTRATIONS OF TRACE METALS IN STACK GAS, GRAINS/DRY STANDARD CUBIC FOOT[a/]

RUN NO.	As	Cd	Cr	Fe	Mn	Ni	Pb
M5-1S	1.65E-7	2.18E-5	3.63E-6	1.10E-4	4.22E-6	< 2.47E-6	2.82E-4
M5-2S	ND	7.98E-6	1.81E-6	1.34E-4	1.05E-6	< 2.61E-6	8.64E-5
M5-3S	ND	7.96E-6	2.12E-6	1.52E-5	0.68E-6	< 2.84E-6	1.21E-4
M5-4S	ND	9.13E-6	< 2.19E-6	3.13E-5	1.40E-6	< 3.28E-6	1.05E-4
MS-5S	ND	2.65E-5	2.89E-6	0.60E-4	3.18E-6	< 3.62E-6	2.50E-4
M5-6S	0.43E-7	2.81E-5	4.78E-6	4.33E-4	1.05E-5	< 3.26E-6	5.05E-4

a/ Symbol (<) indicates below limit of detection

ND Not Determined

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TABLE B-14

MASS EMISSION RATES OF ARSENIC, CADMIUM CHROMIUM, IRON , MANGANESE, NICKEL AND LEAD IN STACK GAS

MASS EMISSION RATES, POUNDS/HOUR[a]

RUN NO.	AS	Cd	Cr	Fe	Mn	Ni	Pb
M5-1S	1.5E-05	4.9E-04	<1.4E-4	4.6E-03	1.7E-04	<2.1E-4	4.1E-03
M5-2S	2.9E-05	1.1E-03	<7.9E-5	5.6E-03	2.8E-04	<1.2E-4	8.9E-03
M5-3S	1.7E-06	5.5E-05	<6.5E-5	1.7E-03	9.1E-05	<1.0E-4	3.7E-03

[a] Symbol (<) indicates below limit of detection.

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TABLE B-15

CONCENTRATIONS OF ARSENIC, CADMIUM, CHROMIUM, IRON, MANGANESE, NICKEL AND LEAD IN STACK GAS

CONCENTRATIONS, GRAINS/DRY STANDARD CUBIC FOOT[a]

RUN NO.	AS	Cd	Cr	Fe	Mn	Ni	Pb
M5-1S	3.6E-07	1.2E-05	<3.3E-6	1.1E-04	4.1E-06	<5.1E-6	9.8E-05
M5-2S	6.1E-07	2.3E-05	<1.7E-6	1.2E-04	6.0E-06	<2.6E-6	19.1E-05
M5-3S	1.7E-07	0.1E-05	<1.6E-6	0.4E-04	2.2E-06	<2.4E-6	9.0E-05

[a] Symbol (<) indicates below limit of detection.

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TABLE B-16

MASS EMISSION RATES OF SELECTED CHLORINATED AND AROMATIC ORGANIC COMPOUNDS BASED ON ANALYSIS OF RESIN SAMPLES, LB/HR

NO.	COMPOUND SAMPLE ID DATE	RT-1S 4-28-87	RT-2S 4-29-87	RT-3S 5-1-87
1.	DICHLOROFLUOROMETHANE	4.9e-5	1.2e-4	7.7e-5
2.	DICHLOROMETHANE	a/	3.9e-4	a/
3.	TRICHLOROFLUOROMETHANE	8.3e-5	3.6e-6	1.4e-4
4.	TRICHLOROMETHANE	a/	a/	a/
5.	1,2-DICHLOROETHANE	a/	a/	a/
6.	1,1,1-TRICHLOROETHANE	2.4e-4	1.5e-4	4.2e-4
7.	CARBON TETRACHLORIDE	a/	a/	a/
8.	1,1,2-TRICHLOROETHYLENE	5.4e-5	3.6e-5	9.5e-5
9.	1,2-DIBROMOETHANE	a/	a/	a/
10.	TETRACHLOROETHYLENE	8.4e-5	8.6e-5	6.7e-4
11.	TRICHLOROTRIFLUOROETHANE	1.9e-4	1.2e-4	8.0e-5
12.	BENZENE	3.4e-4	2.6e-4	1.3e-4
13.	TOLUENE	5.9e-4	5.9e-4	4.5e-4
14.	ETHYL BENZENE	1.4e-4	2.0e-4	1.1e-4
15.	P-XYLENE	1.1e-4	1.7e-4	8.7e-5
16.	M-XYLENE	2.7e-4	3.8e-4	1.9e-4
17.	CUMENE	a/	a/	a/
18.	O-XYLENE	1.5e-4	2.1e-4	1.1e-4
19.	MESITYLENE	5.1e-5	7.5e-5	3.7e-5
20.	NAPHTHALENE	7.7e-5	a/	5.0e-5
21.	METHYL ISOBUTYL KETONE	a/	a/	a/

a/ Below minimum detection level.

TABLE B-17

PCDD/PCDF CONCENTRATIONS IN BOTTOM ASH SAMPLE (ng/g)

RUN #	BA-1S
DIOXINS	
2,3,7,8-TCDD	<0.015
Total TCDD	<0.019
1,2,3,7,8-PeCDD	<0.046
Total PeCDD	0.018
1,2,3,4,7,8-HxCDD	< 0.11
1,2,3,6,7,8-HxCDD	< 0.11
1,2,3,7,8,9-HxCDD	< 0.11
Total HxCDD	0.24
1,2,3,4,6,7,8-HpCDD	< 0.17
Total HpCDD	< 0.17
Total OCDD	< 0.23
FURANS	
2,3,7,8-TCDF	< 0.12
Total TCDF	< 1.7
1,2,3,7,8-PeCDF	0.077
2,3,4,7,8-PeCDF	0.059
Total PeCDF	0.73
1,2,3,4,7,8-HxCDF	< 0.14
1,2,3,6,7,8-HxCDF	< 0.10
1,2,3,7,8,9-HxCDF	< 0.13
2,3,4,6,7,8-HxCDF	< 0.19
Total HxCDF	0.42
1,2,3,4,6,7,8-HpCDF	< 0.17
1,2,3,4,7,8,9-HpCDF	< 0.17
Total HpCDF	< 0.17
Total OCDF	< 0.24

C-86-018

< indicates below the detection limit (MDL)

Test Data for the Refuse Incinerator at Stanford University Environmental Safety Facility, Stanford, CA., California Air Resources Board Test Report, ARB/ML-88-025.

The staff of the California Air Resources board tested the air emissions from a dual chamber Ecolaire refuse incinerator located at the Stanford University Environmental Safety Facility in Stanford, CA. This refuse incinerator has a sodium hydroxide scrubber control system followed by a natural gas fired reheater. These test were conducted from June 29 through July 7, 1987 to determine the emissions from the Stanford refuse incinerator. Test were conducted before (inlet) and after (exhaust) the sodium hydroxide scrubbers. The results of these test are presented in the following tables:

TABLE B-18

DAILY AVERAGE OPERATING PARAMETERS

Date	Trash Rate, LB/HR	Natural[ab/] Gas Use, MM Btu/HR	Lower Chamber Temp., °F	Control Chamber Inlet Temp., °F	Control Chamber Outlet Temp., °F	Control Chamber Outlet Oxygen, Percent
6-30-87	550	4.3	1854	1930	1990	8.6
7-1-87	620	4.3	1964	1998	2059	8.0
7-2-87	725	4.6	1916	1993	2072	7.0
7-7-87	805	4.2	1776	1943	2000	8.8

[a/] Natural gas heat, 1000 Btu/FT^3

[b/] Includes reheater natural gas consumption, 1.2 MM Btu/HR

TABLE B-19

DAILY AVERAGE CONCENTRATIONS OF OXYGEN, CARBON DIOXIDE, CARBON MONOXIDE, OXIDES OF NITROGEN, SULFUR DIOXIDE TOTAL HYDROCARBONS, PARTICULATE MATTER AND HYDROCHLORIC ACID IN THE STACK GAS

DATE	PM	O2 [a/]	CO2 [a/]	CO [a/]	NOX [b/]	SO2 [b/]	HC [bc/]	HCl [b/]
	GR/DSCF	PERCENT	PERCENT	PPMV	PPMV	PPMV	PPMV	PPMV
6-30-87	0.065	9.6	6.7	170	170	NA	160	2.78
7-1-87	0.028	10.6	5.5	(50	NA	NA	(1	0.52
7-2-87	0.029	11.5	6.0	(50	110	NA	2	1.86
7-7-87	-	9.5	7.0	200	100	NA	2	-

[a/] THE O2,CO2 AND CO VALUES WERE USED TO DETERMINE THE MOLECULAR WEIGHT OF THE STACK GAS.

[b/] NOX,SO2 AND HC DATA CORRECTED TO 3 PERCENT O2.

[c/] TOTAL HYDROCARBON DATA REPORTED AS PROPANE.

SYMBOL (() INDICATES BELOW DETECTABLE LIMIT.

NA/ ANALYZER INOPERATIVE.

C-87-022

TABLE B-20

CONCENTRATIONS AND MASS EMISSION RATES OF PARTICULATE MATTER[a]

	SCRUBBER INLET PM, gr/DSCF FRONT	SCRUBBER INLET PM, gr/DSCF BACK	STACK OUTLET PM, gr/DSCF FRONT	STACK OUTLET PM, gr/DSCF BACK
6-30-87	0.028	0.026	0.037	0.028
7-1-87	0.028	0.020	0.024	0.004
7-2-87	0.053	0.021	0.026	0.003

	SCRUBBER INLET PM, LB/HR FRONT	SCRUBBER INLET PM, LB/HR BACK	STACK OUTLET PM, LB/HR FRONT	STACK OUTLET PM, LB/HR BACK
6-30-87	0.421	0.393	0.679	0.512
7-1-87	0.475	0.339	0.442	0.079
7-2-87	0.962	0.377	0.495	0.064

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[a] FRONT indicates the amount of particulate matter found in the Method 5 probe rinse and filter catch. BACK indicates the amount of particulate matter found in the Method 5 after-filter sample recovery.

TABLE B-21

CONCENTRATIONS AND MASS EMISSION RATES HYDROCHLORIC ACID

	SCRUBBER INLET HCl, PPMV	STACK OUTLET HCl, PPMV
6-30-87	628	2.78
7-1-87	538	0.052
7-2-87	759	1.86

	SCRUBBER INLET HCl, LB/HR	STACK OUTLET HCl, LB/HR
6-30-87	6.19	0.034
7-1-87	6.01	0.006
7-2-87	9.14	0.024

TABLE B-22

PCDD/PCDF MASS EMISSION RATES
(ng/sec)

RUN #	DT-1D Scrubber inlet	DT-1S Stack	DT-2D Scrubber inlet	DT-2S Stack
DIOXINS				
2,3,7,8-TCDD	<0.015	<0.029	0.081	<0.020
Total TCDD	0.142	<0.014	1.924	0.279
1,2,3,7,8-PeCDD	0.044	<0.040	0.366	<0.099
Total PeCDD	0.265	<0.068	4.452	1.330
1,2,3,4,7,8-HxCDD	0.092	<0.054	0.350	0.148
1,2,3,6,7,8-HxCDD	0.142	<0.050	0.445	<0.195
1,2,3,7,8,9-HxCDD	0.156	<0.081	0.525	<0.144
Total HxCDD	2.610	<0.080	6.519	3.003
1,2,3,4,6,7,8-HpCDD	3.866	0.179	4.690	1.716
Total HpCDD	7.966	0.318	10.65	4.227
Total OCDD	21.84	0.497	14.20	2.951
Total PCDD	32.82	0.976 **	37.75	11.79
FURANS				
2,3,7,8-TCDF	0.133 *	<0.030	0.816	0.214
Total TCDF	3.174	<0.037	20.57	4.933
1,2,3,7,8-PeCDF	0.546	<0.025	1.733	0.622
2,3,4,7,8-PeCDF	0.702	<0.022	1.779	0.751
Total PeCDF	12.30	<0.138	28.71	10.08
1,2,3,4,7,8-HxCDF	1.200	<0.023	1.933	0.987
1,2,3,6,7,8-HxCDF	1.232	<0.023	1.894	1.137
1,2,3,7,8,9-HxCDF	0.764	<0.028	0.779	0.343
2,3,4,6,7,8-HxCDF	3.243	<0.026	2.926	1.394
Total HxCDF	23.93	0.043	17.43	9.008
1,2,3,4,6,7,8-HpCDF	21.73	<0.032	13.37	4.719
1,2,3,4,7,8,9-HpCDF	2.401	<0.032	1.097	0.386
Total HpCDF	40.19	<0.032	21.08	7.228
Total OCDF	39.61	<0.057	13.14	1.501
Total PCDF	119	0.306 **	101	32.75

NOTES

< indicates below minimum detection limit (MDL)

* - Maximum possible emission rate

** - Total includes MDLs for homologues below the detection limit

TABLE B-22

PCDD/PCDF MASS EMISSION RATES
(ng/sec)

RUN #	DT-3D Scrubber inlet	DT-3S Stack	DT-4D Scrubber inlet	DT-4S Stack
DIOXINS				
2,3,7,8-TCDD	<0.017	<0.010	0.081	<0.045
Total TCDD	0.975	0.176	0.940	<0.019
1,2,3,7,8-PeCDD	0.294	<0.026 *	0.517	<0.094
Total PeCDD	5.956	0.134	6.365	0.111
1,2,3,4,7,8-HxCDD	0.557	<0.038	0.705	<0.207
1,2,3,6,7,8-HxCDD	1.533	<0.040	1.488	<0.188
1,2,3,7,8,9-HxCDD	1.010	<0.033	2.066	<0.173
Total HxCDD	18.67	0.329	18.01	0.357
1,2,3,4,6,7,8-HpCDD	20.85	0.576	18.36	0.244
Total HpCDD	41.75	1.129	38.37	0.613
Total OCDD	75.53	2.986	59.67	0.902
Total PCDD	142.9	4.115	123.4	2.001 **
FURANS				
2,3,7,8-TCDF	0.434	0.026	0.798	<0.109 *
Total TCDF	16.18	0.470	22.18	1.296
1,2,3,7,8-PeCDF	1.376	<0.028	2.867	<0.096
2,3,4,7,8-PeCDF	1.637	0.047	3.987	<0.060
Total PeCDF	27.78	0.230	47.22	0.451
1,2,3,4,7,8-HxCDF	2.351	0.056	6.155	<0.244
1,2,3,6,7,8-HxCDF	2.299	<0.075	6.703	<0.225
1,2,3,7,8,9-HxCDF	1.550	<0.066	4.730	<0.319
2,3,4,6,7,8-HxCDF	4.702	<0.061	14.34	<0.301
Total HxCDF	51.95	0.193	84.32	1.018
1,2,3,4,6,7,8-HpCDF	64.96	0.329	84.28	0.789
1,2,3,4,7,8,9-HpCDF	4.789	<0.031	8.050	0.051
Total HpCDF	107.2	0.494	136.1	1.071
Total OCDF	93.18	0.174	125.9	0.490
Total PCDF	296.3	1.561	415.7	4.327

NOTES

< indicates below limit of detection (MDL)

* - Chemical interference

** - Total includes MDLs for homologues below the detection limit

TABLE B-23

PCDD/PCDF CONCENTRATIONS IN GAS
(ng/dscm corrected to 12% CO_2)

RUN #	DT-1D Scrubber inlet	DT-1S Stack	DT-2D Scrubber inlet	DT-2S Stack
DIOXINS				
2,3,7,8-TCDD	<0.034	<0.062	0.210	<0.042
Total TCDD	0.330	<0.029	4.973	0.589
1,2,3,7,8-PeCDD	0.102	<0.085	0.945	<0.208
Total PeCDD	0.616	<0.144	11.51	2.808
1,2,3,4,7,8-HxCDD	0.214	<0.115	0.904	0.313
1,2,3,6,7,8-HxCDD	0.330	<0.106	1.151	<0.412
1,2,3,7,8,9-HxCDD	0.363	<0.174	1.356	<0.303
Total HxCDD	6.070	<0.171	16.85	6.342
1,2,3,4,6,7,8-HpCDD	8.993	0.383	12.13	3.624
Total HpCDD	18.53	0.677	27.54	8.928
Total OCDD	50.80	1.060	36.71	6.233
Total PCDD	76.35	2.081 **	97.58	24.90
FURANS				
2,3,7,8-TCDF	0.308 *	<0.065	2.109	0.453
Total TCDF	7.383	<0.079	53.19	10.42
1,2,3,7,8-PeCDF	1.269	<0.053	4.480	1.314
2,3,4,7,8-PeCDF	1.632	<0.047	4.599	1.585
Total PeCDF	28.61	<0.294	74.23	21.29
1,2,3,4,7,8-HxCDF	2.792	<0.050	4.998	2.084
1,2,3,6,7,8-HxCDF	2.865	<0.050	4.895	2.401
1,2,3,7,8,9-HxCDF	1.777	<0.059	2.014	0.725
2,3,4,6,7,8-HxCDF	7.542	<0.056	7.563	2.944
Total HxCDF	55.66	0.091	45.05	19.02
1,2,3,4,6,7,8-HpCDF	50.55	<0.068	34.57	9.965
1,2,3,4,7,8,9-HpCDF	5.584	<0.068	2.836	0.815
Total HpCDF	93.48	<0.068	54.50	15.27
Total OCDF	92.14	<0.121	33.96	3.171
Total PCDF	277	0.653 **	261	69.17

NOTES
dscm - dry standard cubic meter at 68 F and one atmosphere
< indicates below minimum detection limit (MDL)
* - Maximum possible concentration
** - Total includes MDLs for homologues below the detection limit

TABLE B-23

PCDD/PCDF CONCENTRATIONS
(ng/dscm corrected to 12% CO_2)

RUN #	DT-3D Scrubber inlet	DT-3S Stack	DT-4D Scrubber inlet	DT-4S Stack
DIOXINS				
2,3,7,8-TCDD	<0.035	<0.018	0.161	<0.075
Total TCDD	2.092	0.323	1.860	<0.031
1,2,3,7,8-PeCDD	0.631	<0.047 *	1.023	<0.157
Total PeCDD	12.77	0.245	12.60	0.185
1,2,3,4,7,8-HxCDD	1.195	<0.069	1.395	<0.345
1,2,3,6,7,8-HxCDD	3.287	<0.073	2.945	<0.313
1,2,3,7,8,9-HxCDD	2.166	<0.060	4.090	<0.288
Total HxCDD	40.04	0.603	35.66	0.595
1,2,3,4,6,7,8-HpCDD	44.71	1.054	36.34	0.407
Total HpCDD	89.53	2.066	75.96	1.022
Total OCDD	162.0	5.466	118.1	1.504
Total PCDD	306.4	7.532	244.2	3.34 **
FURANS				
2,3,7,8-TCDF	0.930	0.047	1.581	<0.182 *
Total TCDF	34.70	0.861	43.91	2.16
1,2,3,7,8-PeCDF	2.951	<0.052	5.677	<0.160
2,3,4,7,8-PeCDF	3.511	0.086	7.894	<0.100
Total PeCDF	59.58	0.422	93.48	0.75
1,2,3,4,7,8-HxCDF	5.042	0.103	12.18	<0.407
1,2,3,6,7,8-HxCDF	4.930	<0.138	13.27	<0.376
1,2,3,7,8,9-HxCDF	3.324	<0.121	9.363	<0.533
2,3,4,6,7,8-HxCDF	10.08	<0.112	28.40	<0.501
Total HxCDF	111.4	0.353	166.9	1.70
1,2,3,4,6,7,8-HpCDF	139.3	0.603	166.8	1.316
1,2,3,4,7,8,9-HpCDF	10.27	<0.056	15.94	0.085
Total HpCDF	230.1	0.904	269.4	1.79
Total OCDF	199.8	0.318	249.3	0.818
Total PCDF	636	2.858	823	7.22

NOTES
dscm - dry standard cubic meter at 68 °F and one atmosphere
< indicates below limit of detection (MDL)
* - Chemical interference
** - Total includes MDLs for homologues below the detection limit

TABLE B-24

MASS EMISSION RATES OF SELECTED METALS IN THE STACK GAS

MASS EMISSION RATES, POUNDS/HOUR

RUN NO.	Cd	Cr	Fe	Mn	Ni	Pb	As	Cr^{+6}
MS-1S	4.24E-4	7.96E-5	12.04E-3	1.11E-4	<7.37E-5	1.51E-2	ND	-
2S	3.46E-4	8.30E-5	1.25E-3	0.51E-4	<7.88E-5	1.47E-2	ND	-
3S	6.71E-4	9.94E-5	3.49E-3	1.12E-4	<8.11E-5	1.78E-2	ND	-
1D	2.61E-4	6.86E-5	0.93E-3	0.53E-4	<5.41E-5	0.53E-2	ND	-
2D	6.74E-4	9.47E-5	1.16E-3	0.55E-4	<4.18E-5	1.55E-2	ND	-
3D	10.63E-4	16.29E-5	1.48E-3	1.27E-4	<4.78E-5	2.55E-2	ND	-
HCl-1S	-	-	-	-	-	-		2.24E-5
2S	-	-	-	-	-	-		10.47E-5
3S	-	-	-	-	-	-		12.23E-5
1D	-	-	-	-	-	-		7.69E-5
2D	-	-	-	-	-	-		<1.04E-5
3D	-	-	-	-	-	-		6.83E-5

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a/ Symbol (<) indicates below limit of detection.

b/ ND indicates none detected.

TABLE B-25

CONCENTRATIONS OF SELECTED METALS IN THE STACK GAS CONCENTRATIONS, GRAINS/DRY STANDARD CUBIC FOOT[a]

RUN NO.	Cd	Cr	Fe	Mn	Ni	Pb	As	Cr^{+6}
M5-1S	2.28E-5	4.28E-6	6.47E-4	5.97E-6	<3.96E-6	8.13E-4	ND	-
-2S	1.88E-5	4.52E-4	0.68E-4	2.80E-6	<4.29E-6	7.98E-4	ND	-
-3S	3.46E-5	5.13E-6	1.80E-4	5.79E-6	<4.18E-6	9.19E-4	ND	-
-1D	1.75E-5	4.61E-6	0.62E-4	3.59E-6	<3.64E-6	3.56E-4	ND	-
-2D	4.00E-5	5.62E-6	0.69E-4	3.27E-6	<2.48E-6	9.21E-4	ND	-
-3D	5.86E-5	8.98E-6	0.82E-4	7.01E-6	<2.59E-6	14.03E-4	ND	-
HCl-1S	-	-	-	-	-	-	-	1.35E-6
-2S	-	-	-	-	-	-	-	5.42E-6
-3S	-	-	-	-	-	-	-	6.05E-6
-1D	-	-	-	-	-	-	-	5.17E-6
-2D	-	-	-	-	-	-	-	<0.62E-6
-3D	-	-	-	-	-	-	-	3.76E-6

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a/ Symbol (<) indicates below limit of detection.

b/ ND indicates none detected.

TABLE B-26

MASS EMISSION RATES OF SELECTED CHLORINATED AND AROMATIC ORGANIC COMPOUNDS BASED ON ANALYSIS OF RESIN SAMPLES (ug/sec)

STANFORD UNIVERSITY

SAMPLE ID DATE	RT-1S 6-30-87	RT-2S 7-2-87	RT-3S 7-7-87	RT-1D 6-30-87	RT-2D 7-1-87	RT-3D 7-2-87
1. DICHLOROFLUOROMETHANE	1.80E+00	3.40E+00	9.68E-01	1.90E+00	1.07E+00	1.16E+00
2. DICHLOROMETHANE	3.24E+01	1.17E+01	1.07E+01	1.40E+01	3.30E+01	1.97E+01
3. TRICHLOROFLUOROMETHANE	< 4.83E-01	< 2.34E-01	1.94E-01	< 2.00E-01	< 1.91E-01	< 2.30E-01
4. TRICHLOROMETHANE	1.02E+01	5.16E+00	4.85E+00	8.99E-01	< 1.91E-01	1.51E+00
5. 1,2-DICHLOROETHANE	5.57E+01	3.29E+01	< 9.70E+00	< 9.99E+00	< 9.72E+00	< 1.16E+01
6. 1,1,1-TRICHLOROETHANE	1.80E+00	9.35E-01	1.45E+00	8.99E-01	1.90E+01	7.19E+00
7. CARBON TETRACHLORIDE	3.54E-01	< 2.34E-01	< 1.94E-01	< 2.00E-01	< 1.91E-01	1.04E+00
8. 1,1,2-TRICHLOROETHYLENE	3.54E-01	2.34E-01	2.88E-01	7.99E-01	3.11E+00	3.71E+00
9. 1,2-DIBROMOETHANE	< 3.54E-01	< 2.34E-01	< 1.94E-01	< 2.00E-01	1.91E-01	2.30E-01
10. TETRACHLOROETHENE	1.26E+00	8.18E-01	1.26E+00	6.99E-01	5.80E-01	3.24E+00
11. TRICHLOROTRIFLUOROETHANE	< 3.54E-01	< 2.34E-01	2.13E+00	6.99E-01	3.40E+00	1.04E+00
12. BENZENE	3.13E+02	6.69E+01	3.06E+01	3.84E+01	6.32E+02 *	2.27E+01
13. TOLUENE	2.10E+01	5.63E+00	1.86E+01	5.68E+00	4.66E+00	5.45E+00
14. ETHYLBENZENE	3.95E+00	2.46E+00	1.94E+00	1.50E+00	1.75E+00	< 1.16E+00
15. P-XYLENE	3.23E+00	1.29E+00	2.32E+00	1.90E+00	4.92E+01	9.43E+01
16. M-XYLENE	8.99E+00	2.23E+00	4.17E+00	1.86E+01	5.70E+01	1.74E+00
17. CUMENE	< 1.80E+00	1.17E+00	1.36E+00	9.19E+00	3.30E+00	4.06E+00
18. O-XYLENE	4.49E+00	2.23E+00	3.00E+00	4.39E+00	2.33E+00	1.62E+00
19. MESITYLENE	1.98E+00	< 1.17E+00	< 9.68E-01	5.00E+00	4.64E+01	4.52E+01
20. NAPHTHALENE	5.39E+00	1.10E+01	3.49E+00	5.29E+00	1.38E+01	5.56E+00
21. METHYLISOBUTYLKETONE	2.01E+01	7.51E+01	< 9.68E-01	**	**	**

* Possible coelution of another unknown compound
** Test results withheld pending confirmation by mass spectrometry
< less than

RT-1S	First Sample in Stack
RT-2S	Second Sample in Stack
RT-3S	Third Sample in Stack
RT-1D	First Sample at Inlet of Scrubber
RT-2D	Second Sample at Inlet of Scrubber
RT-3D	Third Sample at Inlet of Scrubber

TABLE B-27

PCDD/PCDF CONCENTRATIONS IN BOTTOM ASH AND SCRUBBER EFFLUENT

SAMPLE No. a/	B-1 ng/g	B-2 ng/g	B-3 ng/g	S-1 ng/L	S-2 ng/L	S-3 ng/L
DIOXINS						
2,3,7,8-TCDD	<0.015		<0.034			
Total TCDD	2.4	<0.074	0.25	< 0.57	< 4.0	< 0.70
1,2,3,7,8-PeCDD	<0.055 *		<0.045			
Total PeCDD	2.6	< 0.45	0.15	< 0.96	< 3.7	< 2.3
1,2,3,4,7,8-HxCDD	<0.076		<0.059			
1,2,3,6,7,8-HxCDD	<0.091		<0.059			
1,2,3,7,8,9-HxCDD	<0.060 *		<0.059			
Total HxCDD	0.27	< 0.41	0.16	< 1.3	< 1.6	< 2.0
1,2,3,4,6,7,8-HpCDD	0.61					
Total HpCDD	1.4	< 0.48	<0.095 *	< 1.3	< 6.3	< 3.2
Total OCDD	0.76	< 0.24	< 0.14	< 2.4	< 4.0	< 3.5
Total PCDD	7.43		0.56			
FURANS						
2,3,7,8-TCDF	0.20					
Total TCDF	2.5	< 0.18	< 0.14 *	< 0.92	< 1.7	< 0.68
1,2,3,7,8-PeCDF	0.23					
2,3,4,7,8-PeCDF	0.20					
Total PeCDF	2.3	< 0.27	<0.060 *	< 1.3	< 2.2	< 1.9
1,2,3,4,7,8-HxCDF	0.24					
1,2,3,6,7,8-HxCDF	0.20					
2,3,4,6,7,8-HxCDF	<0.077					
1,2,3,7,8,9-HxCDF	0.46					
Total HxCDF	3.1	< 0.24	<0.038 *	< 0.59	< 1.3	< 0.77
1,2,3,4,6,7,8-HpCDF	1.5					
1,2,3,4,7,8,9-HpCDF	< 0.16 *					
Total HpCDF	2.1	< 0.29	<0.081	< 0.96	< 4.4	< 3.4
Total OCDF	0.72	< 0.17	<0.068	< 2.3	< 5.6	< 3.7
Total PCDF	10.72					

Symbol (<) indicates below limit of detection
Symbol (*) indicates chemical interference
a/ B- indicates bottom ash sample
S- indicates scrubber effluant sample

C-87-022